PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 6, NO. 2 ▽ APRIL, 1925

A TYPICAL ELEVATING GRADER-WAGON OUTFIT

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1925

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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

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THE WAGON AND THE ELEVATING GRADER

AN ECONOMIC STUDY OF THE WAGON-ELEVATING GRADER COMBINATION IN THREE PARTS

By J. L. HARRISON, Highway Engineer, U. S. Bureau of Public Roads

PART I

This is the fourth of a series of articles on the factors governing construction costs in the highway field. Other articles will be published from time to time. The Bureau of Public Roads desires that the material presented in these articles shall be as helpful as possible to engineers and to contractors. To that end discussion is cordially invited, either through the engineering press or through this magazine, and any contributions in amplification or in criticism of the facts or the deductions published, if tending to clarify the information presented, to broaden the scope of this work, or to correct deductions thought to be erroneous, will be given appropriate consideration.

IN ANY consideration of the operation of the wagon-elevating grader outfit it is well to remember that the elevating grader is a digging and loading mechanism, and that the wagon is a hauling mechanism. In such an outfit the two styles of equipment perform wholly different functions. In this respect the elevating grader outfit differs somewhat from the older forms of dirt-moving apparatus. Fresnoes and slip scrapers load with the same power that is used in hauling. The wheel scraper requires some additional power for loading—the snatch team—but uses no separate loading device. But in the wagon-elevating grader outfit the grader is primarily a loading device and the production of the outfit as a whole is governed by this apparatus, for, obviously, no more material can be moved by the wagons than can be taken out and loaded by the grader.

The elevating grader was devised for one purpose—to load wagons quickly and economically. The bottom-dump wagon is a much more efficient hauling device than either slips, fresnoes, or wheel scrapers. An ordinary slip, if well loaded, moves about one-fifth of a cubic yard per load, a fresno about one-third of a cubic yard, and a No. 2 wheeler about two-fifths of a cubic yard per load. To move these relatively small amounts, two horses and one man are required in the operation either of a slip or a wheeler while it is engaged in haul. The commonly used 4-foot fresno employs one man and three horses. As compared with this, a standard 1½-yard, bottom-dump wagon hauled by two good horses and in charge of one driver will carry from 1.2 to 1.4 cubic yards, and a 2-yard bottom-dump wagon with a driver and three horses can be loaded to its full rated capacity of 2 cubic yards. These quantities are net, that is, as measured in place, and while they are not always secured under ordinary operating conditions, a failure to secure them is generally due to indifferent supervision of the loading. But, to make effective use of this large advantage in carrying capacity, it is essential that a wagon be loaded quickly and economically. This is the function of the elevating grader and the success of the wagon-elevating grader combination depends on its attainment.

As a digging and loading tool the elevating grader has its peculiar field, which is the handling of clay and loam in level to rather heavily rolling country. It is not well adapted to work in rugged country where the slopes are steep and changes in slope abrupt, and, if the existing cuts are deep, it can not be used to advantage where the work consists largely of widening old roads. Neither is it well adapted, as now commonly designed, for handling sand or for working over wet ground. Its best field is excavation on new location, particularly in those regions, as the Mississippi Valley, where the soils are deep and rock and bowlders are seldom encountered. It does not operate satisfactorily in cut-over land unless the grubbing is so thoroughly done that the larger roots are removed.

THE elevating grader is an excavating and loading machine depending upon wagons for hauling the material which it excavates. In this respect it differs from other types of grading equipment, such as slip scrapers, fresnoes, and wheel scrapers, which haul as well as excavate the earth.

In presenting this study of the operation of the elevating grader-wagon combination the discussion has been divided into three parts; the first of which, dealing with the operation of the grader and the various factors affecting its production, is published in this issue.

Theoretically the capacity of an elevating grader is about 5,000 cubic yards per 10-hour day. Yet many contractors obtain as little as 700 and few attain an average daily production of 1,000 cubic yards. This wide difference between the theoretical and actual production is due to a number of losses, some of which are inherent in the machine itself or the working conditions and, therefore, are unavoidable. Others, however, can be eliminated by careful study and supervision. It is the purpose of this part of the article to explain the nature of these various losses and indicate what may be done to avoid them.

The theoretical capacity of 5,000 cubic yards would be obtained if the grader operated continuously at a speed of 3¾ feet per second without loss of time for a 10-hour day taking constantly a bite with a cross section of 1 square foot and loading all excavated material.

In average practice failure to take a full bite reduces the capacity at once to 2,500 cubic yards. In part this is due to the inefficiency of the bull wheel which transmits power to the plow; in part it is due to the necessity of cutting to a level cross section which, when the original ground level slopes transversely, requires that a shallower bite be taken on the low side of the cut.

Failure to operate at the possible speed of 3¾ feet per second also reduces the quantity of material excavated; and losses of excavated material back of the disk plow and over the sides of the elevating belt still further reduce the material loaded. The fact that the grader does not excavate when turning at the two ends of the cutting loop and time losses in exchanging wagons also subtract from the theoretical capacity.

The wagon-exchange losses are in large part avoidable by proper adjustment of the wagon supply to the length of haul and by requiring the drivers to approach the grader in close order. With lax supervision the time required for the exchange is sometimes as high as 25 seconds. It is generally not less than 11 seconds; but it can reasonably be reduced to 5 seconds.

Inefficient maintenance of the grader resulting in frequent breakdowns, and time lost in cleaning the belt and resting stock still further reduce the production; and these losses especially the first and third, are largely avoidable.

The conclusion drawn from a careful analysis of all losses is that average production can be readily increased from 700 cubic yards a day to at least 1,500 without change in the present design of the grader. By suitable modification of the machine along lines suggested a still greater increase would result.

THE ELEVATING GRADER

In principle, the machine consists of a plow (generally a disk plow) so mounted on a heavy frame, which in turn is mounted on four wheels, that the spoil is dropped on a moving belt by which it is elevated to a height from which it can be dropped into a bottom-dump wagon. Power for driving the belt is picked up by a bull wheel [1] as the apparatus is hauled over the ground either by the 16 to 20 horses required to operate it [2] or by a large tractor. The simple operation of raising the dirt from the ground to the height from which it must be dumped into the wagon requires from 3 to 6 horsepower. As a mechanical device, any bull wheel is highly inefficient; so much so, in fact, that, installed on the elevating grader, it must pick up power at the rate of from 5 to 15 horsepower in order to supply the power needed to elevate the material produced by the plow. This matter is mentioned because it shows why this machine does not function properly in loose, dry sand and in wet ground, its lack of efficiency in such materials being due to the fact that they do not offer enough tractive resistance to enable the bull wheel to supply the power required in operating the belt. Doubtless, as the design of these machines is improved, the models in common use will be provided either with independent power plants for operating the elevating mechanism or, as in the case of the modern harvester, with connections that will make it possible to secure power by direct transfer from the prime mover.

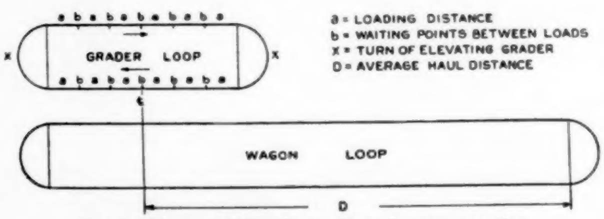

FIG. 1.—Diagram of elevating grader and wagon operation

As the engineer who is estimating a prospective project or a contractor who is working on a project with an outfit of this character, must view his elevating grader as an excavating machine and his wagon supply as a means of hauling the material excavated, his problem is automatically divided into three parts: (1) The production that his grader can secure; (2) the distance the earth must be hauled; and, (3), the wagon supply which must be provided in order to move this production over this distance.

OPERATION OF THE GRADER

As a basis for studying the production of the elevating grader, it may be noted that it is always worked in a loop, i. e., it is hauled back and forth over the area from which material is being taken. This loop is composed of a cut down one side of the area, a turn at the end of the cut, a cut up the other side, and another turn. (See Fig. 1.) Occasionally the lay of the work permits cutting on only one side of the loop; and no material is ever taken out on the turns.

While working along the sides of the loop the operating cycle consists of a period during which the elevating grader is moved forward taking out material, elevating it and depositing it in a wagon which moves alongside, followed by a period during which the grader stops while the loaded wagon moves forward allowing another wagon to move in and take its place. The cutting operation when loading wagons is, therefore, a series of moves forward followed by periods of rest. When casting, no wagons are used and as a consequence the cutting operation between turns is continuous. The speed at which the grader is hauled varies somewhat as between different outfits, but for reasons that will appear later, should be at least 3¾ feet per second.

The cross section of the cut taken out by the plow or disk also varies but, under favorable conditions, may be as high as 1 square foot. Table 1 shows typical stop-watch readings on loading time and miscellaneous data on a project where soil conditions were favorable. A load of 1.35 cubic yards is about 36.5 cubic feet. As, during this study, the grader was being hauled at the rate of 3.62 feet per second, slightly over 0.9 cubic foot of material was delivered to the wagons for each foot of run whenever the loading time dropped to 11 seconds. Allowing for losses of material back of the disk, along the belt, and off the wagons, losses that in good loam are considerable, it is apparent that during this study the cross section at the disk was not infrequently reaching a square foot. This rate of loading is not uncommon if soil conditions are favorable, and may occasionally be slightly exceeded. However, it is not a common thing to find that it is maintained as an average for any considerable time or that it prevails during any large part of the work. It is rather to be viewed as a maximum and therefore as a convenient basis from which to calculate performance.

THEORETICAL CAPACITY OF THE ELEVATING GRADER

The amount that an elevating grader will deliver depends then on a number of things, but it will be apparent that if the cross section of the bite could be consistently maintained at 1 square foot and the speed at 3¾ feet per second, the output of the machine would reach the astonishing rate of 8.3 cubic yards per minute, or about 5,000 cubic yards per 10-hour day, which may be considered as the theoretical capacity of the machine. As many contractors secure a production of as little as 700 cubic yards per day and few indeed attain a daily average of 1,000 cubic yards, there is a wide difference between the theory, as here set down, and actual practice. This difference is caused by losses of one sort or another, and the very magnitude of their cumulative effect suggests their study in some detail.

It will be obvious, almost at a glance, that these losses must fall under one of three headings: (1) Failure to maintain the full cross section while cutting; (2) failure to maintain full speed while moving; and (3) time losses during the working period.

It may be stated categorically that the full cross section of the bite can not be maintained in highway excavation. There are a number of reasons for this. In the first place the cross section of the bite is affected by the soil in which the apparatus is working. In light soil, if the traction is good, the cross section may slightly exceed a square foot. If the soil is heavy and comes off the disk in strips or ribbons, but the traction is good, an almost equally high rate of cutting may be had. But if the soil is such that it tends to clog the belt or if the traction is such that there is more or less slipping of the bull wheel—a very common condition—the cross section must be reduced to a point where the power that can be picked up by the bull wheel is sufficient to elevate the material produced. There is

[1] Designs equipped with an independent power plant for the operation of the belt have been on the market for some years but are not in common use.

[2] The elevating grader is occasionally operated by as few as 12 horses but the result is unsatisfactory, as the normal demand for power when the belt is in full operation exceeds the capacity of 12 ordinary horses, unless the rest periods between loads are long.

also the fact that in many soils, particularly moist clay, the belt fouls badly and as a result tends to slip whenever the load is heavy. This condition works toward a reduction of the bite as whenever it exists the load delivered to the belt must be reduced to a point where the belt will function satisfactorily.

EFFECT OF CROSS SECTION OF CUT ON PRODUCTION

Moreover, the ground worked over is seldom level. When this condition prevails, as it does most of the time, even though the material is otherwise such that a full bite might be taken, it is customary to take a full bite only on one side, because the floor of the cut must be reached on a level cross section. The practical result of this is shown in Table 1. Here (omitting all end loads because they are apt to be affected by tapering off) the loading time averaged slightly over 12 seconds on one side as against 15 seconds on the other side—an increase of 25 per cent in loading time on the low side which of course reflects the smaller bite that caused it.

TABLE 1.—*Typical stop-watch readings on loading time, showing rapid loading, for 16-horse grader with eight 2-horse (1½-yard) wagons*

Average load, 1.35 cubic yards.
Average loading time, 14.9 seconds (343 readings).
Average wagon-exchange time, 16 seconds (296 readings).
Average grader speed, 3.62 feet per second.
Average loading distance, 54 feet.

Loading time, down	Loading time, up	Loading time, down	Loading time, up
Seconds	*Seconds*	*Seconds*	*Seconds*
Turn	Turn	Turn	Turn
28	25	15	15
14	15	11	17
12	15	11	13
13	17	11	14
11	16	14	13
11	20	12	17
12		13	23
12		14	

The manufacturers of elevating graders could reasonably consider a modification of the present design of these machines to enable more rapid lateral adjustment of the plow. With the present designs lateral adjustment is possible but the time required in making the adjustment is too great to permit of its free use. As a result, once the width of the bite is set the shaker can control directly only its depth, which he does by raising or lowering the plow. Consequently, as these machines are commonly operated, if the bite is set 10 inches wide and it is possible to make a cut 14 inches deep on the high side, which will give a cross section of approximately 1 square foot, the cross section on the low side will be reduced in proportion to the amount which must be subtracted from the full depth of the bite in the interest of leveling, since no change is made in the width of the bite. As an illustration, if a cut 3.5 feet on one side and 2.5 feet on the other is to be taken out by standard methods in three levels, the difference between the amount of material secured per foot of run as between the high side and the low side will be about 30 per cent.

If, however, instead of following the custom, the plow is set for a bite wider than normal, the tractor can be driven a little farther from the bank on the high side, thus reducing the width of the bite to normal, and a relatively wide bite may be taken on the low side by merely driving the tractor in normal relation to the bank. The result of following this general practice is to secure a more nearly uniform, as well as a higher, average rate of bite and so a higher average rate of loading. This can be done if the prime mover is a caterpillar tractor, but when horses are used it is difficult of accomplishment.

There is still, of course, the fact that in bringing a cut to grade the layers will taper longitudinally. This further complicates the problem for there must be, on this account, a selection of the length of run for each level and, in general, a tapering out of the bite (see Table 1) at the end of the run. Regardless of other conditions, therefore, it is not possible in highway work either to secure a unform bite or consistently to secure a full bite, but the best shakers give much thought to keeping it as uniform and as large as possible, and the men who are successful in doing this are well worth the relatively high wages they receive.

DEFECTS OF ELEVATING GRADERS

It may be pertinent to mention in this connection that the substitution of tractors for horse-drawn equipment has been hindered by the inadequacies in the design of the elevating grader which have been noted above. The elevating grader was originally designed as a horse-drawn apparatus and as such has functioned quite satisfactorily. It also functions reasonably well with a large caterpillar tractor, for it is a valuable and, on the whole, an effective tool wherever it can be appropriately used. However, the full advantage of the caterpillar tractor as a prime mover will not be secured until the elevating grader is redesigned in some particulars. Basically, the weak points in this machine are the absolute dependence of its elevating mechanism on the bull wheel and the tendency of the belt to foul, which causes it to slip. The performance of the bull wheel depends on the nature of the material over which the machine is operated. It, therefore, follows that no matter how much power is available for hauling the grader and for taking out the large bite necessary if output is to be kept at a maximum, the bite, and therefore the output, is still dependent on the traction which the bull wheel has on the soil over which it is working, and the ability of the machine to transmit this power to the belt. The full advantage of the tractor as a prime mover will not be available to the contractor until the design of the grader is so modified in these particulars that the splendid power plant of the modern caterpillar tractor can be effectively utilized in forcing the grader to pick up and elevate a full load without regard to soil conditions.

The studies made by the bureau's engineers show that under average working conditions a 1½-cubic yard bottom-dump wagon is loaded in about 75 feet (net load measured in place in the cut about 1.3 cubic yards). This indicates that as compared with a cross section of 1 square foot, which the machine can take out under good working conditions, the amount of material placed on the wagons averages a little less than 0.5 cubic foot per foot of run, indicating an effective cutting cross section of slightly less than 0.5 square foot. In other words, the 5,000-cubic yards theoretical daily capacity of the machine is reduced by rather more than 2,500 cubic yards, partly because of general working conditions, in no small degree because of basic inadequacies in the design of the machine itself, and to a considerable degree through inattention to that vitally important detail—the bite. The fact that so large a

part of the theoretical capacity of the machine can be lost in this way should serve to emphasize the necessity of giving the closest attention to the bite in order to insure, under all circumstances, the taking of the largest possible bite.

This matter might be of less importance were it not for the fact that, to all intents and purposes, the elevating grader is a constant-speed machine. All of the studies made on horse-drawn equipment indicate that when working under load the speed of operation becomes quite uniform. The same general observation applies to tractor-drawn equipment. The general practice is to establish a working speed and then maintain that speed. Moreover the power output required of the horses is so high that there would be little possibility of increasing the speed to offset a deficiency in the amount of load taken per foot of run, even if other conditions made such a course possible. But, even if ample power were available, there is no possibility of securing any relief in this way because the grader must be operated within the speed at which a wagon can be hauled alongside for loading. Therefore the failre to take out a full bite causes a loss of time and so of output, which can not be compensated by faster moving. Indeed, this loss can not be regained by efficiency in any other part of the work. It is a dead loss.

REDUCTION OF OUTPUT BY SLOW TRAVEL

The next point at which output is lost involves the speed at which the grader is moved. Later on in this article the speed at which the wagons are commonly operated will be discussed in some detail, but it may be observed here that the ordinary walking speed of a team hauling a loaded wagon is from 240 to 250 feet per minute, or about 4 feet per second. The wagon box of an ordinary bottom-dump wagon is a little more than 6 feet long. Loading should begin as soon as the belt is clear of the driver and, while driving at normal speed, the wagon should gain enough on the grader to bring the belt over the back of the wagon by the time the load is finished. This requires the wagon to move about 4 feet farther than the grader during the loading period. This relationship will obtain if the wagon travels about a quarter of a foot per second faster than the elevating grader. The grader should, therefore, maintain a rate of travel of at leat 3¾ feet per second.[3] This rate can be and is maintained by horse-drawn outfits employing 20 horses (see Table 2), but is not generally maintained by the standard 16-horse outfit.

Caterpillar tractors normally maintain a speed of about 3 feet per second, which is about 25 per cent low. This defect is not traceable to any inadequacy in the power plant, but rather to poor governing, which it should be a very simple matter to remedy; but the effect is, nevertheless, to produce a direct loss in excess of 20 per cent in the rate of output, efficiency in other parts of the work being equal, for elevating graders of the design now in common use are not capable of handling any increased bite at this lower speed with which to compensate this loss. Therefore, the contractor who is operating his elevating grader at less than 3¾ feet per second owes his second loss in yardage to this loss, and this, like the loss due to a small bite, is one that can not be compensated by special efficiency in any other part of his work.

[3] This is based on the assumption that the bite will be maintained at a reasonably high average. If the average bite is small, the difference between wagon speed and grader speed should of course be correspondingly reduced, or, in other words, the speed of the grader should be slightly increased.

TABLE 2.—*Typical grader speeds*

Prime mover	Study No.	Number of study periods [1]	Average grader speed
			Feet per sec.
Caterpillar tractor	13	14	2.9
	17*b*	34	3.3
	18*a*	1	3.1
	18*b*	20	2.8
	20	8	2.9
	23	10	3.0
16-horse team	13	18	3.2
	15	9	3.3
	18	5	3.1
	19	22	3.6
	21	3	3.3
	22	6	2.8
20-horse team	18	5	3.8
	41	5	3.9

[1] The study period was generally 1 hour.

TURNING LOSSES NOT TO BE OVERLOOKED

The third item of loss is loss of time. This occurs at a good many points and in a good many ways. Of these the first is the turn at each end of the grader loop. The time consumed in making a turn may be taken as about 45 seconds and the loss of time due to this cause will run from over 60 per cent of the total time, if the cuts are so short that only one load can be taken on each side, to as little as 6 or 7 per cent as the cuts lengthen to 1,000 feet. If the turn could always be made as a half circle, it could be accomplished in from 30 to 35 seconds. The fact is, however, that the length of productive run on the two sides of the loop is not always the same Where it is not the same the grader has a certain distance to travel on one side of the loop without taking out material. It is a matter of indifference whether the time required for this unproductive run is charged to miscellaneous losses or to turning time. In the bureau's studies it has been charged to turning time because it occurs just before or just following the turns, and on this account the recorded turning time varies a good deal from project to project. In spite of this variation it appears reasonable to consider the turning time, including unproductive run, at 45 seconds. With good superintendence and a fortunate arrangement of material in the cuts, this time may be bettered, but some cases will also be found where the lay of the material to be moved is such that the turn can not consistently be kept within this limit.

While the time consumed is relatively large, the loss due to inefficiency or carelessness in making turns is relatively small on most jobs. On some, however, it does amount to a good deal and can be avoided. As the grader is not under load while turning, the forward gig of a horse-drawn grader can be unhooked and driven around at a trot and the other horses may reasonably be forced to a speed somewhat greater than would be expected when traveling under full load. As between the 16-horse outfit which makes the turn without releasing the forward gig and allows the horses to turn at their pulling pace and the outfit on which the forward gig is removed and the balance of the outfit brought up to a lively walking pace, there is a difference of some seconds in the average turning time.

If caterpillar tractors are used, the turning time is about the same as for horses. This is contrary to the general impression, but results from the fact that the radius of the turn is largely governed by the grader and the ground conditions rather than by the flexi-

bility of the prime mover. In general, the tractor does turn the grader on a somewhat shorter radius than the horses, but as the tractor is ordinarily operated at a slower rate this saving is largely offset. On the other hand, the tractor in high gear can travel quite as fast as the horses even when driven at a rapid walk. It is so easy to shift the tractor into high gear that is is surprising to find that no effort is made to do so on the majority of the jobs. A little time is taken in shifting gears, so the net saving is not large where only the turn is to be accomplished, but if there is in addition any considerable unproductive run, the saving is of more importance. Table 3 shows the turning time on a number of jobs.

TABLE 3.—*Time required to turn elevating graders*

Prime mover	Study No.	Turning time	Remarks
		Seconds	
Caterpillar tractor	13	56	Slow work.
	14	60	Long unproductive runs.
	18*b*	48	Normal.
	20	64	Bad working conditions.
	23	48	Normal.
	30	36	Little unproductive run.
	31*a*	54	An old worn-out machine, very slow.
	31*b*	48	Normal.
16-horse team	13	59	Slow work.
	14	65	Long unproductive run.
	15	45	Normal.
	18	44	Do.
	19	48	Do.
	21	44	Do.
	22	59	Wet ground and slow outfit.
	40	44	Normal.
20-horse team	18	49	Operations a little slow.
	41	43	Normal.

Turning time always is an important factor in output, but it is particularly so when cuts are short. Tables 4 A, 4 B, and 4 C show this quite clearly. If short cuts are common, the percentage of time spent in turning is relatively high and output falls off. If short cuts and short haul are combined with long cuts and long haul, to handle which a contractor carries a large number of wagons, his situation is particularly unfortunate. This matter will be more fully developed in another part of this article, but is here referred to in order to lay stress on the fact that turning time is a factor which the contractor can not afford to overlook. It reduces the output which he can obtain on short cuts and is one of the reasons that light work often fails to yield the expected profit and that projects in localities where elevating graders are uncommon should be carefully scrutinized if it is the intention to use elevating graders in their execution. In such localities it is safe to assume that projects are designed for construction with other types of earth-moving equipment, and contractors accustomed to handling projects that have been designed for elevating graders may easily overlook the fact that the average length of cut and the relative amount of side borrow on a project designed for fresnoes and wheelers is likely to be quite different from the similar items on an elevating grader job.

TABLE 4.—*Effect of length of cut on output and on relation between turning time and working time*

A. AVERAGE MANAGEMENT WITH 1½-CUBIC-YARD WAGONS

[Loading distance, 75 feet; loading time, 23 seconds; exchange time, 18 seconds; time losses, 10 per cent]

N. B.—A loading loop consists of a run down the cut, a turn, a run up the cut, and a second turn. In developing Tables 4 A, B, and C, a half loop—one run and one turn—has been used. By this device the "length of cut" may be compared directly with plans for construction work. The output in loads per hour and the percentages of working time and time used in turning are the same as they would be if the whole loop were used.

Number of loads	Length of cut	Wagon-loading time	Wagon-exchange time	Grader turning time	Time losses due to breakdowns, rests, etc., 10 per cent	Total time	Loads per hour	Percentage of total time used in turning grader	Percentage of time grader is at work
	Feet	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Number*	*Per cent*	*Per cent*
1	75	23		45	7	75	48	60.0	30.6
2	150	46	18	45	11	120	60	37.5	38.3
3	225	69	36	45	15	165	65	27.3	41.8
4	300	92	54	45	19	210	69	21.4	43.8
5	375	115	72	45	23	255	71	17.6	45.0
6	450	138	90	45	27	300	72	15.0	46.0
7	525	161	108	45	31	345	73	13.0	46.7
8	600	184	126	45	36	391	74	11.5	47.1
9	675	207	144	45	40	436	74	10.3	47.5
10	750	230	162	45	44	481	75	9.3	47.8
15	1,125	345	252	45	64	706	76	6.4	48.9
20	1,500	460	342	45	85	932	77	4.8	49.4

B. GOOD MANAGEMENT WITH 1½-CUBIC-YARD WAGONS

[Loading distance, 60 feet; loading time, 16 seconds; exchange time, 5 seconds; time losses, 5 per cent]

1	60	16		45	3	64	56	70.3	25.0
2	120	32	5	45	4	86	84	52.4	37.2
3	180	48	10	45	5	108	100	41.7	44.5
4	240	64	15	45	6	130	111	34.6	49.2
5	300	80	20	45	7	152	118	29.6	52.6
6	360	96	25	45	8	174	124	25.8	55.2
7	420	112	30	45	9	196	129	22.9	57.2
8	480	128	35	45	10	218	132	20.6	58.8
9	540	144	40	45	11	240	135	18.7	60.0
10	600	160	45	45	13	263	137	17.1	60.9
15	900	240	70	45	18	373	145	12.1	64.4
20	1,200	320	95	45	23	483	149	9.3	66.4

C. GOOD MANAGEMENT WITH 2-CUBIC-YARD WAGONS

[Loading distance, 90 feet; loading time, 24 seconds; exchange time, 5 seconds; time losses, 5 per cent]

1	90	24		45	4	73	49	61.6	32.9
2	180	48	5	45	5	103	70	43.7	46.6
3	270	72	10	45	6	133	81	33.8	54.1
4	360	96	15	45	8	164	88	27.4	58.5
5	450	120	20	45	9	194	93	23.2	61.9
6	540	144	25	45	11	225	96	20.0	64.1
7	630	168	30	45	12	255	99	17.6	65.9
8	720	192	35	45	14	286	101	15.7	67.2
9	810	216	40	45	15	316	103	14.2	68.4
10	900	240	45	45	17	347	104	13.0	69.2
15	1,350	360	70	45	24	499	108	9.0	72.2
20	1,800	480	95	45	31	651	111	6.9	73.6

Another loss of time comes in loading the wagons. The time required to load a wagon depends on the cross section of the bite, the speed at which the grader is drawn, and the percentage of material that reaches and remains on the wagons. The first two of these items have been noted and discussed above. The third, the percentage of material which is delivered to and retained on the wagons, while perhaps of minor importance, nevertheless is of sufficient significance to warrant attention. Material is lost in important quantities back of the disk, along the edge of the belt, and by spilling from the wagon. The first of these losses is sufficient to justify manufacturers in considering a more effective design, particularly around the lower end of the belt. Contractors often avoid some of the loss of material which takes place at this point by placing a steel plate over the rather wide opening back of the disk. This simple expedient serves to save a good many loads of material during the course of a day's work, particularly if the machine is working in light soil. No convenient method of measuring these losses has been devised, but from such observations as have been made it appears that they may amount to from 5 to 10 per cent of the material taken out by the disk, particularly in light loam and in sandy soils.

When the bite is such that wagons are loaded in 75 feet, a grader speed of 3 feet per second results in a loading time of 25 seconds. If the grader speed is 3¾ feet per second, the loading time is 20 seconds. The average loading time as determined by the studies is about 23 seconds. If the bite is increased so that a load can be had in 60 feet, and the grader speed is maintained at 3¾ feet per second, the loading time drops to 16 seconds. As a production of 600 to 700 loads per day is quite common, the cumulative effect of slow loading is considerable.

PROMPT EXCHANGE OF WAGONS ESSENTIAL

Another important factor in any summary of time losses is the period during which wagons are exchanged at the grader. This exchange period averages about 18 seconds (see Table 5). It includes the most conspicuous and, perhaps, the most easily avoidable losses which the contractor encounters in elevating grader work. Theoretically, it is possible to exchange wagons in about 4 seconds, if the replacement wagon follows the loading wagon with the noses of the horses hard against the tailboard. From the horses' heads to the back of the driver's seat is about 14 feet and, allowing 3 feet for the width of the belt, the replacement team has only to move about 17 feet to spot the next wagon which, at ordinary walking speed, requires a little over 4 seconds. As a matter of observed practice (see Table 6C), the wagon exchange may be made within this time. As compared with this attainable exchange period, however, it is found that the exchange time is generally not less than 11 or 12 seconds over any extended period, even though the wagon supply is adequate, and often when the wagon supply is inadequate the time required is much greater, as may be seen from Table 5.

Table 5.—*Effect of wagon supply on exchange time*

Study number	General average exchange time	Average exchange time when wagon supply was adequate	Study number	General average exchange time	Average exchange time when wagon supply was adequate
	Seconds	*Seconds*		*Seconds*	*Seconds*
13	17.2		18d	21.4	
13a		11.6	19	16.0	
13b		13.3	20	17.9	10.1
14		10.8	21	38.1	12.8
14a	18.0		22	51.8	11.6
15	15.8	14.0	23	10.2	7.5
17a	19.2		30		7.8
17b		7.1	31a	22.0	
18a	8.9		31b	18.2	
18b	34.7	11.5	40	13.5	
18c	21.0	9.9	41	9.0	

The common failure to exchange wagons within a reasonable period, say within an average of 5 seconds, is due to a number of causes. Of these, the first is a positive inadequacy in the wagon supply. For the effect of this see Table 6A. Conversations with numerous contractors leave the impression that there is a surprising tendency to view the elevating grader as a piece of equipment which can be used to load a train of wagons—that is, that the wagon train is the basis on which calculations are made. The correct view, of course, is that the elevating grader is the primary tool and that the wagon supply should be selected to handle all the material the grader can be made to produce. If the wagon supply is inadequate it is, of course, impossible to keep the exchange time down because the time spent in making an exchange is governed by the rate at which the wagons can be supplied to the grader.

An equally important factor is the superintendence. The lack of good superintendence is quite as conspicuous on elevating grader work as in the operation of other types of earth-moving equipment. On the jobs studied it has been the rule rather than the exception to find replacement teams walking from 20 to 100 feet behind the wagons which they are to replace. If a team is 40 feet behind its leading wagon, 10 seconds are required at the customary walking rate of 4 feet per second to reach the point from which the exchange should have begun; that is, the tailboard of the loading wagon. These 10 seconds must be added to the 4 seconds which are required for the move forward from the tailboard of the loading wagon to the loading position. The larger part of the difference between the proper exchange time and the actual exchange time when the wagon supply is adequate is to be accounted for in just this way.

Table 6.—*Stop-watch readings of wagon exchange time*

A. SHOWING HIGH EXCHANGE TIME OCCASIONED BY INADEQUATE WAGON SUPPLY WITH CONSEQUENT LOW PRODUCTION

Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump	Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump
Seconds	*Seconds*	*Seconds*	*Seconds*
15	13	22	17
15	11	15	14
8 min. 50 sec.[1]	8	12	15
[1] 32	15	12	7 min. 50 sec.[1]
10	18	15	10
15	20	25	
1 min. 0 sec.[1]	12		

[1] Grader waiting for wagons.

Average wagon exchange time, 56 seconds; loading distance, 55 feet; number of loads per hour, 51; length of cut, 275 feet; wagon-haul distance, 1,600 feet.

B. SHOWING UNNECESSARY DELAY IN EXCHANGE TIME WHEN CUTTING AWAY FROM DUMP OCCASIONED BY IMPROPER TURNING OUT OF LOADED WAGON

Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump	Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump
Seconds	*Seconds*	*Seconds*	*Seconds*
7	25	10	23
8	26	6	23
8	25	7	32
7	27		
8	30	Average 7.4	Average 26.0
6	23		

Length of cut, 660 feet; wagon-haul distance, 1,000 feet.

C. SHOWING AVERAGE EXCHANGE TIME OBTAINABLE WITH GOOD MANAGEMENT

Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump	Wagon exchange time cutting toward dump	Wagon exchange time cutting away from dump
Seconds	*Seconds*	*Seconds*	*Seconds*
6	6	4	5
4	5	4	7
4	4	6	5
5	4	5	4
5	5		
6	4	Average 4.9	Average 4.9

That part not so accounted for is attributable to one of two causes. The first is the common failure to insist that the load shall be finished with the belt over the end of the wagon. If it is finished with the belt just back of the driver, it is hard to make the exchange in less than 6 seconds. The second is the manner in

which the loaded wagon is turned out when the grader is moving away from the dump. If while working in close quarters this turn is made before the replacement wagon is in loading position, the exchange takes about 25 seconds. (See Table 6B.) If however, the loaded wagon is driven ahead at an angle until the replacement wagon can reach the loading position and then stands until the loading wagon and its replacement pass, the loss of time affects only the loaded wagon. The grader waits for the next wagon no longer than on the trip toward the dump. Figure 2 shows the correct turn and two incorrect turns.

Proper position of replacement wagon for prompt wagon exchange

Improper position of replacement wagon for prompt wagon exchange

It should be observed in this connection that if a contractor has supplied a wagon train with an elevating grader under the presumption that his exchange period will approximate 18 seconds and then, by careful supervision, endeavors to reduce his exchange time to a correct average—5 seconds or under—he will find that he is more or less handicapped in doing this because saving nearly a quarter of a minute per load by the reduction of his exchange time will at once create a deficiency in the wagon supply. This is mentioned because it has been observed that contractors who have endeavored to reduce the exchange time have, in some instances, more or less abandoned the effort as impossible of attainment because of this fact. There is little use in trying to put snap into the wagon exchange unless there are enough wagons on the job so that savings made through efficient exchange are not at once obliterated by inadequacy in the supply.

RELATION OF WAGON SUPPLY TO LENGTH OF HAUL A CONTROLLING FACTOR IN EXCHANGE TIME

Securing an exchange period of 5 seconds will not prove a simple matter. A brief study of Figure 1 will show the reason for this. The loading loop varies in length from one so short that only one load can be taken on each side, to a loop 1,000 feet or more in length. The wagon loop also varies in length in the same way. Take, as an illustration, a loading loop 500 feet in length from which the haul is in one direction to a point 500 feet below the lower end of the loading loop. Under these conditions the wagon haul will vary from 500 to 1,000 feet in length and will average something over 750 feet. If, therefore, the wagon supply is calculated on the basis of the actual average haul, it will be excessive at some points and deficient at others. In order to obviate this difficulty the contractor should require empty wagons to trot to position whenever necessary to place a wagon in position behind the loading wagon before the load is completed. If the wagon supply is adequate for the actual length of haul involved, this will enable an efficient superintendent to avoid loss of time in the exchange of wagons.

If the wagon supply is adequate for the average haul prevailing, there need be no fear that the stock will be injured by this practice. However, if trotting is habitually practiced in order to increase production in the face of a deficient wagon supply, the effect on the stock is likely to be disastrous, and such a practice is not to be recommended. There is a difference between this and the practice of trotting the teams for the purpose of adjusting an adequate average wagon supply to the fluctuating length of wagon haul that is a necessary feature of elevating grader work. A horse can turn out a large amount of power or work at a rapid rate for a short time if the rest periods are such that the day's output of power is not excessive. Trotting, in order to adjust the wagon supply to the changing haul distance, is within his normal capacity and may reasonably be practiced, for the extra speed required on one trip will be offset by a corresponding period of

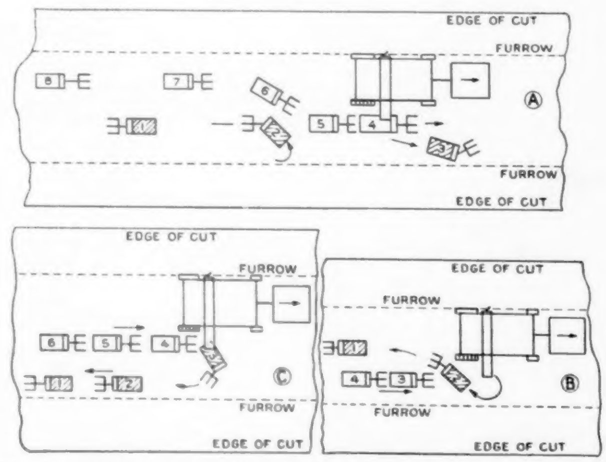

FIG. 2.—Methods of turning loaded wagons away from grader: A. The correct method. No time lost by grader. B. Incorrect method in a narrow cut. Time lost by grader about 20 seconds. C. Incorrect method in a wide cut. Time lost by grader about 10 seconds.

rest on the next. But if the wagon supply is inadequate, there is no corresponding rest period, for the time gained in trotting results in a positive increase in the power output required during each working period. If the power output resulting from this practice is uniformly excessive over any extended period, the stock will be correspondingly damaged.

MISCELLANEOUS DELAYS

Finally, delays of one sort or another account for time losses of considerable importance. These fall principally under three headings—breakdowns, cleanouts, and rests.

Breakdowns occur rather frequently on elevating grader work. The chain drives give the most trouble. The belt gives more or less. Other parts break occasionally. Lack of proper maintenance is the outstanding cause of this trouble. Instead of buying a new set of chains for the belt drive every spring, the old set will be continued in service until it is replaced link by link as it breaks on the job. It takes only two or three minutes to repair such a break but, in the meantime, a dollar's worth of output has been lost. On one job the writer found the grader standing idle and the crew in camp. The rear axle had broken—not an uncommon occurrence—and the job had been delayed the better part of a week because no extra axle was on hand. On another job the grader was idle because the main drive pinion had worn out. The contractor had known of its condition for weeks, but hoped it would last a little longer. The repairs cost both the contractor and his men a good deal more than they would had they been made at the proper time. To pay a dollar a link, in lost time, for repairing drive chains, to lose a week's time because repair parts are not on hand, or to hope that a worn-out pinion will somehow last a few weeks longer are all illustrations of the general tendency to undermaintain the elevating grader, a tendency that expresses itself in constantly recurring breakdowns with their attending loss of time.

Elevating graders are often continued in service long after they have become so badly worn that breakage is frequent and trouble with the elevating mechanism more or less chronic. The result is not only the definite time losses noted above, but a constant, rather intangible loss of efficiency rather hard to prove definitely, which expresses itself in a number of ways. Thus, contractors often object to the operation of tractors at speeds as high as 3¾ feet per second on the ground that when obstructions are encountered the grader is likely to be broken. Of course, if the grader itself is in good condition, this is a matter which can readily be obviated by using a proper spring coupling between the grader and the tractor and, on new machines, by an appropriate redesign of the devices by which the plow itself is held in place. These objections reflect the fact that many of the graders now in use are light and more or less worn out, and that there is a valid reason to fear the result of placing the machine under heavy strain.

This same general observation applies to the objection, often raised, to taking a full bite in heavy ground when other conditions would permit; that is, that the grader is not strong enough to stand the heavy strain thus imposed on it. For many of the machines now in use, this is no doubt the case. But, as the objective is yardage at the lowest possible cost, it is poor economy to continue an old machine in service if this can be done only by accepting a reduction in output. At current prices, a substantially built machine can be had for the money secured from the movement of from 8,000 to 10,000 cubic yards of material. The loss of as little as 50 or 60 yards a day during the construction season will cover the entire cost of a substantial machine—a very small amount when considered in the light of the heavy reduction in rate of output which attends any reduction in the bite.

It is not necessary to multiply illustrations in order to emphasize the point that the tendency to reduce production in order to get along with a worn-out machine often generates intangible losses of even greater importance than the positive time losses due to breakdowns. The remedy is obvious. Obsolete and worn-out graders should be replaced and a good grader should receive the attention needed to keep it always at a high point of efficiency.

The clean out around the lower roller stops the outfit a good many times every day. In moist clay soils it is sometimes necessary to clean the whole bottom side of the belt. These operations are caused by the tendency of droppings to accumulate just above the bottom roller and on the belt itself. These accumulations, which cause the belt to function improperly, must be removed from time to time—occasionally as often as once for every 10 or 15 wagons loaded. The clean out takes from a minute to three or four minutes. In the course of a day's work the loss of time from this cause may therefore be considerable. It is not, however, an avoidable loss with the present design of the grader.

RESTING STOCK

Another delay, involving heavy losses, results from the resting of stock. This is most conspicuous when the grader is drawn by 16 horses. Not much will be said on this point, as the dynamometer studies now in progress should yield precise information on the power output required. It may be observed, however, that, whereas the time losses on caterpillar-tractor jobs tend to run in the neighborhood of 5 per cent and are caused almost entirely by grader breakdowns and clean outs, the time losses on horse-drawn jobs sometimes exceed 20 per cent in hot weather. As clean-out losses are independent of the motive power and breakdowns certainly no more frequent on the horse-drawn jobs, the importance of these rest periods from the standpoint of output will be apparent.

The horse as a power unit has certain limitations, it appears, which tend to interfere with high production. When 16 horses are attached to an elevating grader, it is possible for them to develop the power necessary in order to load wagons promptly if the rest periods between loads are long enough. But when the weather is hot or the flow of power becomes more constant, i. e., as increasing efficiency of superintendence tends to reduce the wagon-exchange period, the burden placed on a 16-horse outfit tends to become excessive and the extra rest periods must be taken. These, of course, tend to offset any advantage secured from reduced wagon-exchange time. For this reason if an effort is to be made to develop high efficiency additional horse power ordinarily must be supplied. This is particularly true during the summer months. Observations of 20-horse outfits tend to establish the fact that an outfit of this size can endure the increased strain incident to high output. But even when 20 horses are used rest periods may have to be permitted during hot weather. It is here that the caterpillar tractor shows its great advantage. It does not tire as the percentage of time under full load is increased and hot weather has no adverse effect on it. Where a high degree of efficiency is to be maintained and with it a high rate of output, the caterpillar tractor offers a source of power at once dependable and effective. Its slow rate of travel, while a disadvantage, by no means outweighs this advantage, and, in any event, there is no reason to suppose that its speed is necessarily slower than that of well-driven horses.

In summarizing the question of time losses due to breakdowns, clean outs, and resting stock, it may be noted that these losses vary over rather wide limits due to soil conditions, the age of the machines worked, weather, etc. In general, 5 per cent may be appropriately allowed on caterpillar-tractor jobs of which, normally, less than half will be clean out losses. If 16 horses are to be used on the grader, another 5 per cent should be added for resting stock on a full-season job where soil conditions are good. If the job is short and is to be done during hot weather, 10 per cent should be allowed in normal loam and clay, but if the ground is heavy, even 15 per cent may be inadequate.

PRACTICES THAT EAT INTO THE WORKING DAY

The losses discussed above affect production during the working period. In addition to these losses the contractor not infrequently accepts practices which effectively reduce the working period itself. This may be illustrated by citing the practices on a job where the nominal working period was 10 hours. The men understood that 10 hours work was required and fractional days were paid for on that basis. The contractor made it a practice to move camp about every four miles, working some two miles in each direction from the camp, which resulted in an average trip to and from camp of about a mile. This trip at the ordinary walking speed for the horses took about 20 minutes. It was the custom to make the trips out—morning and noon—on the contractor's time and the return trips on the men's time. Here then, was a direct loss of 40 minutes of working time every day. Also, it was customary to water the stock morning and afternoon. This stopped operations for from 15 to 25 minutes twice a day—a net loss of perhaps 40 minutes a day. Watering stock during the working period is not a general practice among contractors, even during hot weather, but the fact that it is sometimes done with no modification of the nominal daily working period suggests that where managerial practices of this sort prevail the working period should not be considered 10 hours. In this case it really averaged about 8 hours and 40 minutes.

It has been pointed out that, on work of this sort, losses are not recoverable. If the bite is small there is a loss of time and output because too much time is used in loading the wagons. If the speed of the grader is too low there is the same effect. If time is lost in wagon waits or in delays, output is reduced because fewer loads can be taken out. In all of these cases the losses are positive and cumulative, for the men employed must be paid as much and the horses will eat as much when the production is low as when it is high. This also applies to lax managerial policies. The contractor who is paying for 10 hours of work and getting only 8⅔ hours is suffering a direct loss which will appear as a corresponding reduction in output.

THE SITUATION SUMMARIZED

Summarizing the situation briefly, there are comparatively few contractors now operating elevating graders who succeed consistently in obtaining an average output much over 60 loads an hour. Many contractors never consistently reach this output. But, as compared with this rate of output, there is no apparent reason why, by careful attention to the speed at which the grader is moved and the bite that it takes, a load can not be consistently put onto a wagon in 16 seconds and an exchange of wagons made in 5 seconds which, with due allowance for turns, and the elimination of unnecessary delays, should enable an efficient contractor to produce a load every 30 seconds or 120 loads an hour. In order to secure such a rate of production the principal requirements are an adequate wagon supply and really competent superintendence. In Table 7 the relationships which have been discussed are set down so as to show the effect of these various elements on output. An examination of this table will show that if a large output is to be secured it must be done by taking a consistently heavier bite, by maintaining a proper grader speed, by making a prompt wagon exchange and by reducing the time losses to a minimum.

TABLE 7.—*Effect of various losses on elevating grader output*

	Grader speed 3¾ feet per second			Grader speed 3 feet per second		
	Bite 40 per cent	Bite 50 per cent	Bite 60 per cent [1]	Bite 40 per cent	Bite 50 per cent [2]	Bite 60 per cent
Theoretical maximum production of grader at plow, cubic yards per 10-hour day	5,000	5,000	5,000	4,000	4,000	4,000
Rate at which material is delivered by grader while it is loading wagons, cubic yards per 10-hour day	2,000	2,500	3,000	1,600	2,000	2,400
For 1½ cubic yard wagons:						
Portion of grader time spent in loading wagons (based on average length of cut of 450 feet) ... per cent	-------	-------	-------	50	45	42
Portion of grader time that can, under good management, be spent in loading wagons (450-foot cut) ... per cent	62	60	58	-------	-------	-------
Resulting average production per 10-hour day as now obtained ... cubic yards	-------	-------	-------	800	900	1,010
Average production per 10-hour day reasonably possible with good management ... cubic yards	1,240	1,500	1,740	-------	-------	-------
For 2 cubic yard wagons:						
Portion of grader time spent in loading wagons (based on average length of cut of 450 feet) ... per cent	-------	-------	-------	57	53	50
Portion of grader time that can, under good management, be spent in loading wagons, (450-foot cut) ... per cent	64	63	62	-------	-------	-------
Resulting average, production per 10-hour day ... cubic yards	1,280	1,575	1,860	910	1,060	1,200

[1] Contractors should endeavor to work in this field.
[2] Contractors now customarily work in this general field.

The relations shown in Table 7 are based on a 450-foot loading loop. During the past working season studies, some short and some covering a period of a month or more, were made on more than 20 separate outfits. The average length of cut during these studies (the loading loop) was almost exactly 450 feet. But, as between the various studies, the length of cut averaged under 300 feet on 2, between 300 and 400 feet on 5, between 400 and 500 feet on 5, between 500 and 600 feet on 3, and over 600 feet on 5.

Tables 4A, 4B, and 4C give additional data on the production that can be secured with average superintendence and high-class superintendence for various lengths of cut. As it is wholly impossible to secure as great an output on short cuts as on long ones, it seems

(Continued on page 41)

PROCEDURE FOR TESTING SUBGRADE SOILS

A DESCRIPTION OF THE REVISED METHODS ADOPTED BY THE BUREAU OF PUBLIC ROADS

By J. R. BOYD, Assistant Engineer of Tests U. S. Bureau of Public Roads

METHODS employed by the Bureau of Public Roads in testing subgrade soils were first described in a paper by A. T. Goldbeck and F. H. Jackson in the Proceedings of the American Society for Testing Materials, volume 21, 1921. A more complete description was given by the writer in a paper published in the Proceedings of the American Society for Testing Materials, volume 22, 1922, entitled "Physical Properties of Subgrade Materials." Since the publication of this description a number of changes have been found desirable, and these changes are incorporated in the following description of the revised methods.

PREPARATION OF SOIL SAMPLES

1. The sample as recieved from the field is dried in an oven at a temperature not exceeding 100° C. (212°F.) It is then broken up in a mortar by means of a pestle (preferably rubber-covered), care being taken not to break any of the rock fragments, and passed through a ¼-inch screen. The fractions passing and retained on the screen are then weighed separately and the weight of the latter, expressed as a percentage of the weight of the entire sample, is recorded for use in the mechanical analysis. If it is desired to keep the material retained by the ¼-inch screen, it should be kept separate from the remainder of the sample.

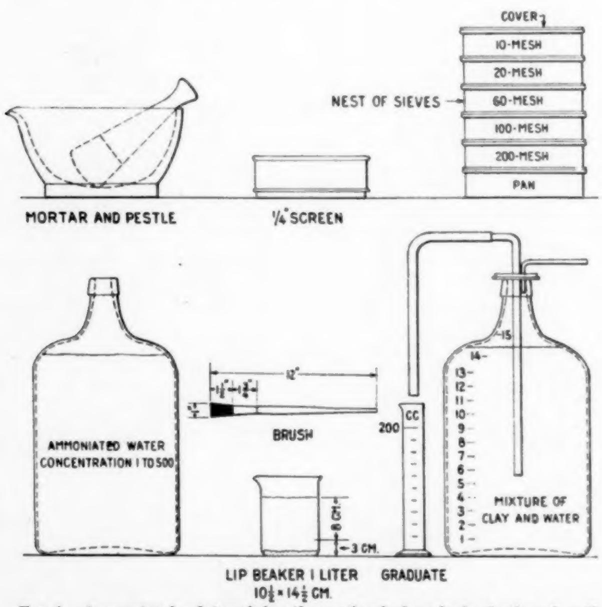

FIG. 1.—Apparatus for determining the mechanical analysis of subgrade soils

2. From the material passing the ¼-inch screen, a sample is selected, by the method of quartering, sufficiently large to make as many of the subgrade tests as may be desired. This sample is passed through the 10-mesh sieve, and the material retained on this sieve is discarded. With the exception of the mechanical analysis all subgrade tests are made on material which passes the 10-mesh sieve.

MECHANICAL ANALYSIS

In making a mechanical analysis (the apparatus employed is shown in Fig. 1) of subgrade soils, four fractions are determined; namely, coarse material, sand, silt, and clay. These terms are defined as follows:

Coarse material is all material retained above the 10-mesh sieve.

Sand is that material which passes a 10-mesh sieve, is retained on the 200-mesh sieve, and subsides through a height of 8 centimeters in ammoniated water (concentration 1:500) in 8 minutes.

Silt is that material, which passes a 200-mesh sieve, and subsides through a height of 8 centimeters in ammoniated water (concentration 1:500 in 8 minutes.

Clay is that material which passes a 200-mesh sieve and which does not subside through a height of 8 centimeters in ammoniated water (concentration 1:500) in 8 minutes.

It has been found by experience that a more accurate mechanical analysis is obtained if the analysis is made on material passing the ¼-inch screen instead of material passing the 10-mesh sieve. The reason for this is that without the action of water it is impossible to separate completely the fine material from that retained on the 10-mesh sieve. In view of this fact the mechanical analysis is made in the following manner:

From that part of the entire sample which has passed the ¼-inch screen, as described in paragraph 1, "Preparation of Soil Samples," a sample is selected, by the method of quartering, weighing approximately 50 grams.

This sample is placed in an oven and dried to constant weight at a temperature not exceeding 100° C. (212° F.). After cooling to room temperature in a desiccator it is weighed and placed in a beaker with approximately 500 cubic centimeters of distilled water. (Where clear tap water is available, distilled water is not necessary.) This mixture is gradually brought up to the boiling point during a period of one hour and allowed to simmer for an additional hour, but actual boiling should be avoided. After standing until cool the supernatant liquid is decanted to a depth of 3 centimeters above the bottom of the beaker into a large vessel (10 to 20 liters). Ammoniated water (concentration 1:500) is then added to the beaker to a height of 11 centimeters and the material is thoroughly brushed and dispersed with a stiff brush for a period of 1 or 2 minutes and then allowed to stand for 8 minutes. The supernatant liquid is then decanted to a depth of 8 centimeters from the surface of the liquid into the large vessel. Ammoniated water is again added to the beaker, brushing repeated as before, and after 8 minutes sedimentation, the supernatant liquid is decanted again into the large vessel. This process is repeated until the supernatant liquid becomes clear after 8 minutes sedimentation. The "sand" and "silt"

have now been separated from the "clay" which is contained in the large vessel. The material in the beaker (sand and silt) is transferred to an evaporating dish and dried to constant weight at a temperature not exceeding 100° C. (212° F.), cooled in a desiccator and a sieve analysis made, using the 10-mesh, 20-mesh, 60-mesh, 100-mesh, and 200-mesh sieves. The time of shaking for the sieve analysis is 15 minutes.

The material retained on the 10-mesh sieve is coarse material and should be expressed as a percentage of the entire sample in order that it may be added to the percentage of material retained on the ¼-inch screen, thus giving the total percentage of coarse material existing in the original sample. This is accomplished by subtracting the percentage of material retained on the ¼-inch screen from 100 and multiplying the percentage of material retained on the 10-mesh sieve, as determined from the small sample, by the factor obtained from this subtraction.

The percentage of "sand," "silt," and "clay" should be computed on the basis of the weight of the fine material only, which means that the weight of the material retained on the 10-mesh sieve should be subtracted from the weight of the small sample before computing the percentages of the fine material.

The large vessel is thoroughly shaken until all material is in suspension. Two hundred cubic centimeters of the liquid are then siphoned from approximately the center of the liquid into a graduate. The liquid is transferred from the graduate to an evaporating dish, evaporated to dryness, and the weight of the clay residue determined. This weight multiplied by the factor obtained by dividing the total volume of liquid by 200 represents the total weight of clay in the sample, and this weight should be expressed as a percentage of the fine material by dividing it by the weight of the material passing the 10-mesh sieve.

The sum of the percentages of sand and silt subtracted from 100 should equal the percentage of clay as actually determined. A maximum error of 3 per cent is allowable In order that the analysis may total 100 per cent, the error should be distributed logically among the fractions.

The actual determination of clay may be eliminated, and the percentage may be computed from the following formula:

$$\frac{\text{Original weight of fine material} - (\text{weight of sand} + \text{weight of silt})}{\text{original weight of fine material}} \times 100$$

but this method should be used only as a last resort since it eliminates the check.

MOISTURE EQUIVALENT TEST

The moisture equivalent of a soil is defined as the amount of moisture, expressed as a percentage of the dry weight of the sample, retained by a soil when it is subjected to a centrifugal force equal to 1,000 times the force of gravity. The apparatus used in the test is shown in Figure 2, and the procedure for determining the moisture equivalent is as follows:[1]

A 5-gram sample of the soil, prepared as described under "Preparation of soil samples," paragraph 2, is placed in a Gooch crucible, the bottom of which has been previously covered with a piece of filter paper, and allowed to take up moisture until completely saturated. It is then placed in a damp closet over night to insure a uniform distribution of moisture throughout the soil mass, after which the crucible is placed in a Babcock cup, in the bottom of which is a rubber stopper, shown in Figure 2, with a hole through its center sufficiently large to hold the water thrown out by the centrifuge. Besides receiving the ejected water, the stopper also serves as a cushion. The Babcock cup is provided with a brass cap to prevent evaporation. The sample is centrifuged for a period of one hour, at a speed which, for the diameter of head used, will exert a centrifugal force 1,000 times the force of gravity, upon the center of gravity of the soil sample. Immediately after centrifuging, the sample is weighed, dried in an oven to constant weight at a temperature not exceeding 100° C.

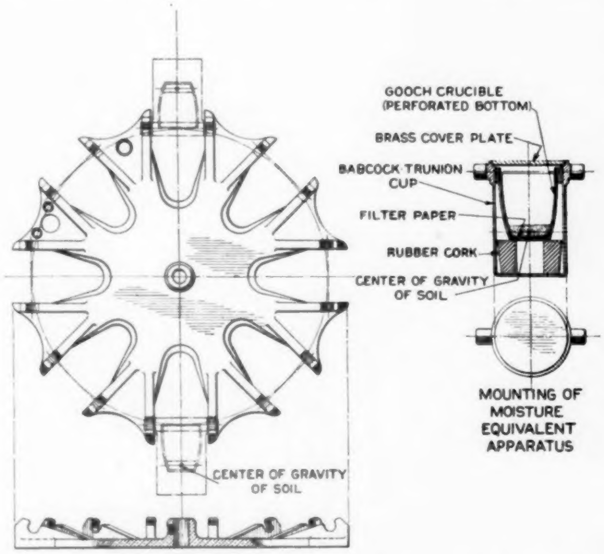

FIG. 2.—Apparatus for determining the moisture equivalent of subgrade soils

(212° F.), and a second weight determined. The moisture equivalent of the soil is calculated from the following formula:

$$\text{Moisture equivalent} = \frac{(A - b) - (A^1 - b^1)}{A^1 - (a + b^1)} \times 100$$

in which

A = weight of crucible and contents after centrifuging.
A^1 = weight of crucible and contents after drying.
a = weight of crucible.
b = weight of filter paper wet.
b^1 = weight of filter paper dry.

The test should always be made upon duplicate samples and these should be placed opposite to each other in the centrifuge, care being taken to accurately counterbalance them.

The variation between the two values obtained should not exceed 1 per cent for values of the moisture equivalent up to 15 per cent, and 2 per cent for values above 15 per cent.

[1] A practical field test for determining the approximate moisture equivalent percentage of soils is described in Public Roads, vol. 5, No. 6, August, 1924, p. 10.

CAPILLARY MOISTURE TEST

The capillary moisture of a soil may be considered as the amount of moisture the soil is capable of taking up against the force of gravity. All subgrade soils have the ability to take up capillary moisture to some extent, and it is for the purpose of determining the relative amounts which can be taken up by subgrade soils of varying characteristics that the following test is used. The apparatus is shown in Figure 3.

A sample of the soil, prepared as described under "Preparation of soil samples," paragraph 2, is dried to constant weight in an oven at a temperature not exceeding 100° C. (212° F.), allowed to cool in a desiccator, and then poured loosely into a glass tube

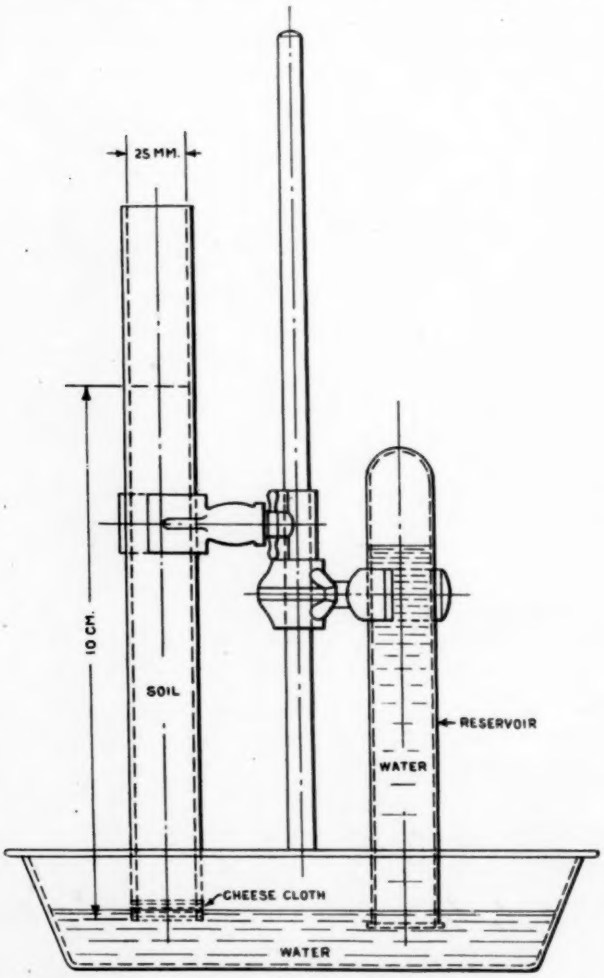

FIG. 3.—Apparatus for the capillary moisture test

(inside diameter 25 millimeters), the bottom end of which has previously been covered with cheesecloth. The tube is jarred until the soil reaches a height of 10 centimeters and no further settlement takes place. The lower or covered end of the tube is then just immersed in water. When capillary moisture reaches the top of the soil column, the tube is weighed daily until it comes to constant weight. (A slight fluctuation in weight is to be expected due to barometric changes.) The percentage of capillary moisture is then computed from the following formula:

$$\text{Percentage of capillary moisture} = \frac{(A - A^1) - (b - b^1)}{A^1 - (a + b^1)} \times 100$$

in which

A = (weight of glass tube) + (wet soil) + (cheesecloth and rubber band wet).
A^1 = (weight of glass tube) + (dry soil) + (cheesecloth and rubber band dry).
a = weight of glass tube.
b = weight of cheesecloth and rubber band wet.
b^1 = weight of cheesecloth and rubber band dry.

VOLUMETRIC SHRINKAGE TEST

A very important characteristic of subgrade soils is their relative shrinkage when moisture is withdrawn from them. The test for determining this characteristic is made in the following manner:

A sample of soil, prepared as described under "Preparation of soil samples," paragraph 2, is thoroughly mixed with a given quantity of water and placed in a small, flat, cylindrical, porcelain dish approximately 6 centimeters in diameter and 1 centimeter deep and struck off with a spatula. (The porcelain dish should be greased with a film of vaseline, or similar material, previous to filling it with soil.) The sample is then allowed to dry in the air and is weighed at frequent intervals until no further loss of weight is recorded. If desirable the sample may be placed in the oven after air drying for 24 hours.

The percentage of volumetric contraction of the soil is determined as follows: The weight of mercury required to just fill the porcelain dish is obtained, as well as the weight of mercury which is displaced by the soil pat after shrinkage takes place.

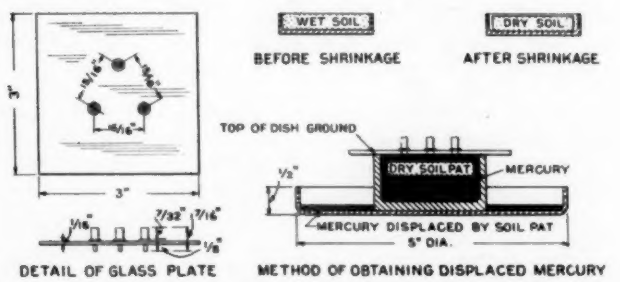

FIG. 4.—Apparatus for determining the volumetric shrinkage of subgrade soils

The volume of mercury required to just fill the porcelain dish and also the volume displaced by the soil pat is determined by means of the apparatus shown in Figure 4. The weights of these two volumes are also determined, denominated A and B, respectively, and the volumetric shrinkage of the soil is computed from the following formula:

$$\text{Percentage of volumetric shrinkage} = \frac{A - B}{A} \times 100$$

Two samples are always prepared for each soil and the average result considered as the percentage of volumetric shrinkage of the soil.

In some cases it may be desirable to know the percentage of lineal shrinkage; consequently, a curve has been prepared, Figure 5, showing the relation between the percentage of volumetric shrinkage and the percentage of lineal shrinkage.[2]

[2] A practical field method for determining the lineal shrinkage of soil is described in Public Roads, vol. 5, No. 6, August, 1924, p. 12.

COMPARATIVE BEARING VALUE TEST

This test is used for determining the *comparative* bearing power of soils and should not be considered as indicative of the actual field bearing power. It is made in the following manner:

The soil, prepared as described under "Preparation of soil samples," paragraph 2, is mixed by hand with the desired amount of water. The mixture is thoroughly kneaded for several minutes in order that complete distribution of the moisture may be obtained. It is then covered with a pan and allowed to stand for 15 minutes, after which it is placed in a cylindrical brass container and subjected to an initial load of 10 pounds per square inch to insure uniformity of compaction. (Fig. 6.) After putting the 1-square-inch bearing block in position the container is mounted in the bearing value apparatus (Fig. 7) so that the point of application of the load on the horizontal beam is 0.1 inch above the position of equilibrium. The sand for applying the load is released and simultaneous readings of load and penetration are made for each one-tenth-pound increment of load, the maximum penetration used being 0.2 inch. As the point of equilibrium of the system corresponds to a dial reading of zero, the beam is displaced 0.1 inch above the true horizontal position at the beginning of the test and 0.1 inch below at the end of the test. Load readings as obtained from the spring balance must be multiplied by 4, due to the ratio of the lever arms. Check tests are run on each soil, and from the average of these the bearing value curve is plotted. For comparative purposes the bearing value of the soil. is taken as the load in pounds per square inch required to produce a penetration of 0.1 inch.

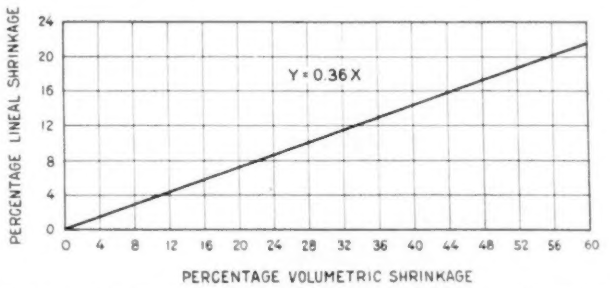

FIG. 5.—Relation between percentage of volumetric shrinkage and percentage of lineal shrinkage of subgrade soil

SLAKING VALUE TEST

The rapidity with which a soil slakes down under the action of moisture is considered as one of its important characteristics and is determined in the following manner:

A sample of the soil prepared as described under "Preparation of Soil Samples," paragraph 2, is thoroughly mixed with its moisture equivalent moisture and molded, under a pressure of 1,875 pounds per square inch, into a briquette $1\frac{1}{8}$ inches in diameter and $1\frac{1}{16}$ inches in height. (Fig. 8.) The briquette is allowed to dry in the air for approximately 18 hours and is then oven dried to constant weight at a temperature not exceeding 100° C. (212° F.). On being removed from the oven it is placed in a desiccator until cool and then tested by means of the apparatus shown in Figure 8. The slaking value is taken as the time required for the briquette to slake sufficiently to fall through the brass ring. Two specimens are made on each soil and the average considered as the slaking value of the soil.

NOTE.—*The briquettes are made $1\frac{1}{8}$ inches in diameter and $1\frac{1}{16}$ inches in height in order to produce, after shrinkage takes place, a briquette approximately 1 inch in diameter and 1 inch high. It has been found that approximately 35 grams of the soil and water mixture are required to produce a briquette of the desired size. The actual weight can only be determined by trial.*

DYE ADSORPTION TEST

It has been found that soils which appear to be practically identical, on mechanical analysis can give entirely different results for the moisture and volumetric tests. This indicates that the character of the material, especially of the clay, as well as its grading, has an important influence upon the physical characteristics of the soil. In order to determine the relative character of different soils, Dr. E. C. E. Lord, of the Bureau of Public Roads, has devised the following test:

A small sample of soil (about 10 grams), prepared as described under "Preparation of Soil Samples," paragraph 2, is oven dried to constant weight at a temperature not exceeding 100° C. (212° F.) and allowed to cool in a desiccator. The actual weight of soil used in this test is determined by the character of the soil, 0.5 gram being used for soils low in clay and 0.2 gram for those which are high in clay. Should it be difficult to judge the amount of clay, it is advisable to make a trial test. After cooling, a sample of the proper size, as determined above, is carefully weighed and transferred, by means of a camel's-hair

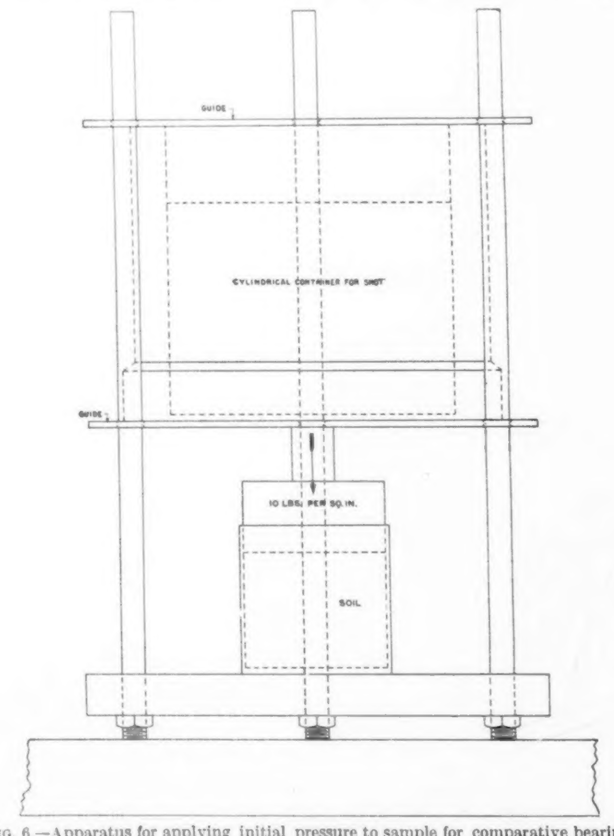

FIG. 6.—Apparatus for applying initial pressure to sample for comparative bearing value test

brush and glass funnel, into a separatory tube of about 5 cubic centimeters capacity which contains approximately 1 cubic centimeter of the dye solution. This mixture is thoroughly stirred with a polished glass rod for the purpose of coagulating the soil particles, causing them to settle out of the liquid. Stirring is continued until no soil particles are left in suspension, more dye solution being added, if necessary, to accomplish this result. The coagulated mixture is then introduced into a filter tube by means of the separatory funnel. (Fig. 9.) The filter tube should have been previously capped with filter paper and water allowed to run through it in order to prevent the trapping of air. The amount of water thus used should be determined in order that a correction may be made for it at the completion of the test. After the dye solution used for coagulation purposes has drained through the soil, additional dye should be added. Filtration should be allowed to continue until a marked discoloration appears in the filtrate. This indicates the end of the test, and the volume, in cubic centimeters of colorless filtrate, should be recorded. This volume less the cubic centimeters of water used in washing the filter tube, when converted to a basis of 1 gram of soil, represents the dye absorption number of the soil.

NOTE: *The dye employed in this test is a solution of 1 part of basic analine dye (methyl violet) in 1,000 parts of distilled water. The solution should be prepared in quantities of about 1 liter in order that a uniform solution may be provided for a large number of tests. Light and age materially affect the character of the dye solution, which consequently should be protected from strong light and should never be used when over 2 months old.*

INTERPRETATION OF TEST RESULTS

The interpretation of the results of tests on subgrade materials must, necessarily, be very general until sufficient field data can be obtained to make possible an accurate correlation of the test results with the observed behavior of the soil in the field. The limited research which has been given to the problem to date has yielded some very interesting conclusions, however, and it is confidently expected that, as more data are obtained, it will ultimately be possible to predict the field behavior of subgrade soils from an interpretation of the physical characteristics of the soils, as determined by laboratory tests.

The following comments should prove helpful in interpreting the results of tests on subgrade materials. It is advisable, however, that each investigator interpret the results in the light of his own experience, until sufficient data have been collected to permit the formulation of specific conclusions relative to the significance of the tests.

Mechanical analysis test.—The mechanical analysis is for the purpose of determining the gradation of the soil; i. e., the relative amounts of sand, silt, and clay contained in the soil. By itself, this test is not significant except in a very general way. It is known, of course, that soils containing a large percentage of clay (roughly, above 30 per cent) are, in general, undesirable, while those containing a small percentage (roughly, less than 30 per cent), as a rule, make good subgrades.

Moisture equivalent test.—This is one of the most important of the subgrade tests. It provides the means of comparing directly the relative ease with which subgrades of different characteristics may be drained. Soils that have high moisture equivalents are relatively more difficult to drain than those which have low moisture equivalents.

The deduction drawn from a recent investigation conducted by the Bureau of Public Roads in the Pacific Northwest was that soils that have moisture equivalents above 20 are undesirable as subgrade materials. Although this investigation was confined

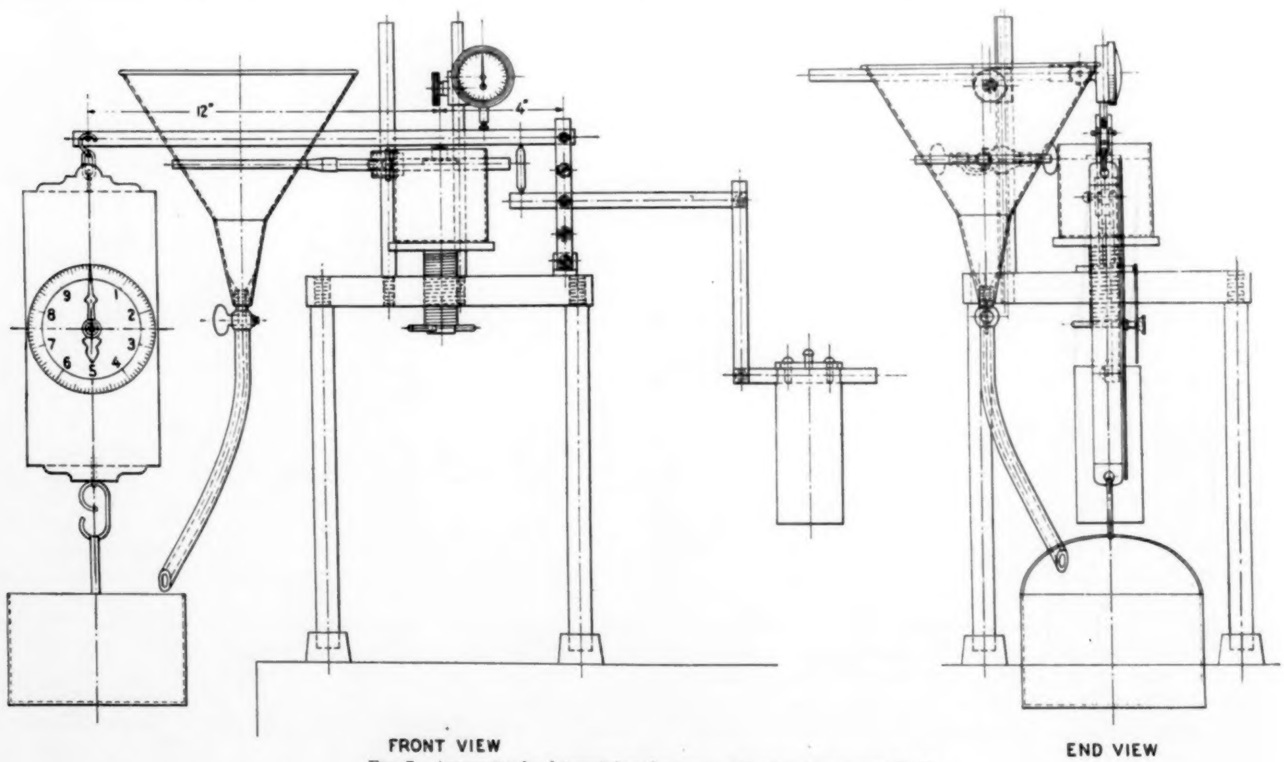

FIG. 7.—Apparatus for determining the comparative bearing power of soils

to a small section of the country, it is felt that the value of 20 is approximately correct as the line of demarcation between good and bad subgrade soils.

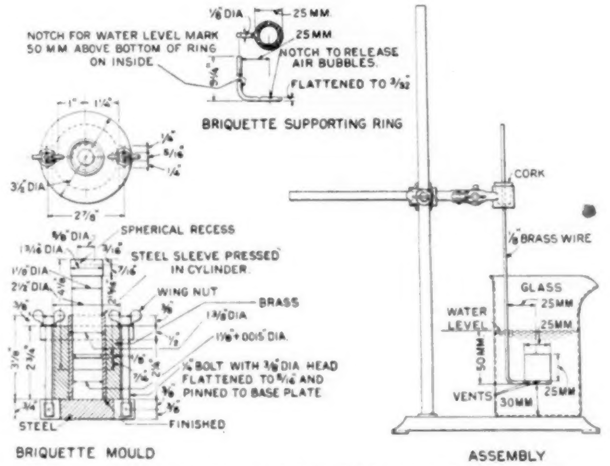

FIG. 8.—Apparatus for determining the slaking value of subgrade soils

Capillary moisture tests.—An effort is now being made to correlate the values obtained from this test with maximum moisture conditions existing in the field. Data so far collected seem to indicate that the maximum field moisture percentage of a soil is somewhat above the capillary moisture percentage as determined in the laboratory.

Volumetric shrinkage test.—The volumetric shrinkage of a subgrade soil should be determined under maximum field moisture conditions. Until more definite information is obtained, the capillary moisture as determined in the laboratory will be considered as approximating the maximum field moisture and the volume change test will be made under this moisture condition. Available information seems to indicate that subgrade soils having a percentage of volumetric shrinkage greater than 15 per cent will not make desirable subgrades.

Comparative bearing value test—Up to the present time it has been impossible to correlate this test with any field data so far obtained. Consequently this test should be considered only as a laboratory method for determining the comparative bearing value of subgrade soils.

Slaking value test.—The slaking value test should give information relative to the ability of subgrade soils to withstand the slaking action of water. Owing to the fact that this test has only been recently standardized it is not possible to give any limiting values at this time.

Dye adsorption test.—The dye adsorption test gives an indication of the character of the clay existing in the subgrade. It is quite possible to obtain approximately similar mechanical analyses from two different subgrade soils, and yet these soils may react in an entirely different manner to the other physical tests. This is due, undoubtedly, to the difference in character of the constituent parts of the soil, especially the clay. A soil having a large percentage of very active clay will give an adsorption number higher than that obtained from a soil having approximately the same percentage of less active clay. High percentages of clay accompanied by high adsorption numbers almost invariably indicate poor subgrade material.

In general it may be said then that soils having a high moisture equivalent, a high capillary moisture percentage, a high volumetric shrinkage, and a high dye adsorption number will be very poor as a subgrade material, while if these values are low the material may be expected to give satisfactory service.

(Continued on page 41)

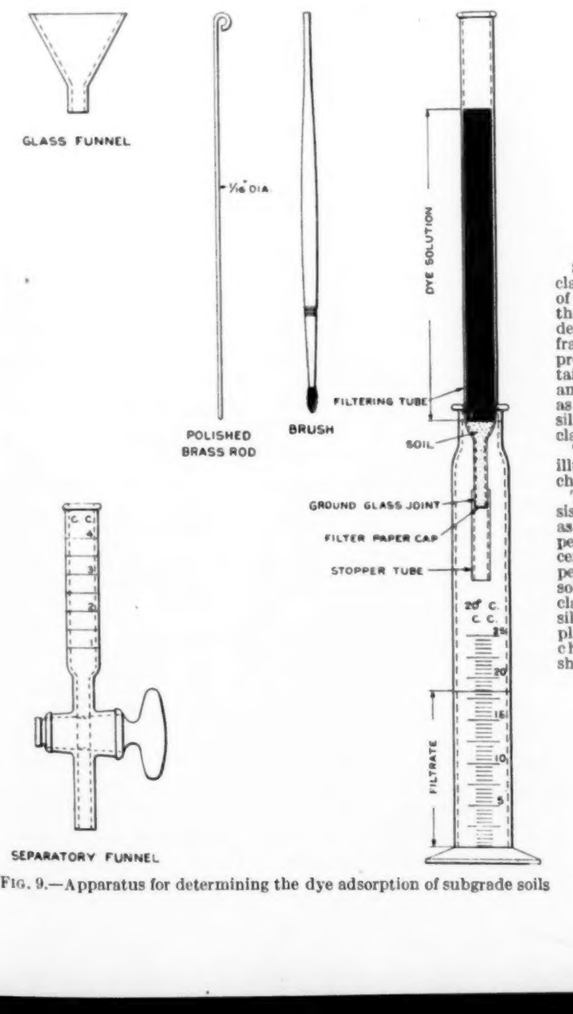

FIG. 9.—Apparatus for determining the dye adsorption of subgrade soils

EXPLANATION OF CHART

Subgrade soils are divided into six classes, according to the relative amounts of sand, silt, and clay which exist in them, the name of the class being determined by the predominating fraction and modified by the next predominating fraction as obtained from the mechanical analysis. This gives six classes as follows: Silty clay, sandy silt, sandy clay, clayey sand, clayey silt, silty clay.

The following example illustrates the use of the chart.

The mechanical analysis of a subgrade soil is as follows: Sand, 20 per cent; silt, 30 per cent; and clay, 50 per cent. This soil would be classified as a silty clay and plotted on the chart as shown.

DEFINITIONS

Sand is that material which passes a 10-mesh sieve, is retained on the 200-mesh sieve and subsides through a height of 8 cm. in ammoniated water (concentration 1 to 500) in 8 minutes.

Silt is that material which passes a 200-mesh sieve and subsides through a height of 8 cm. in ammoniated water (concentration 1 to 500) in 8 minutes.

Clay is that material which passes a 200-mesh sieve and which does not subside through a height of 8 cm. in ammoniated water (concentration 1 to 500) in 8 minutes.

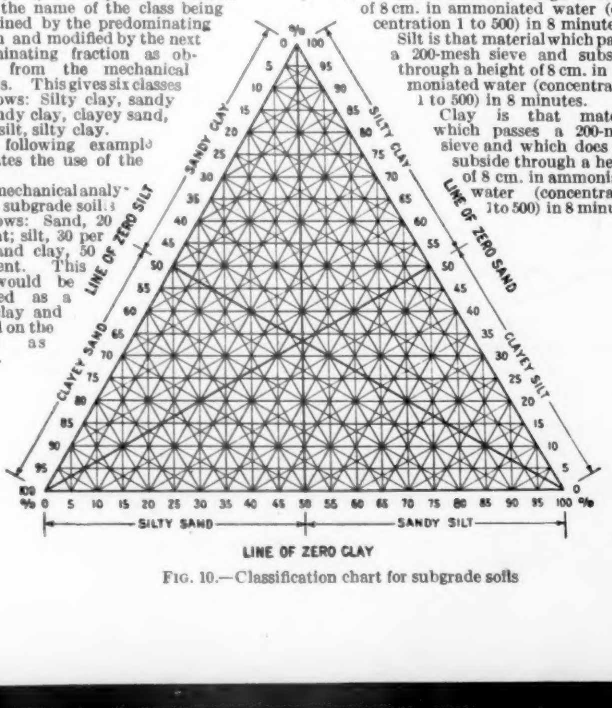

FIG. 10.—Classification chart for subgrade soils

TAR SURFACE TREATMENT OF GRAVEL ROADS[1]

A DESCRIPTION OF A NEW METHOD DEVELOPED BY THE WISCONSIN HIGHWAY COMMISSION

By N. M. ISABELLA, Maintenance Engineer, Wisconsin Highway Commission

IN 1923 the Wisconsin Highway Commission developed a new method of surface treating gravel roads and tested the process experimentally on a mile of road. The value of the new method lies principally in the fact that by its use a deeper penetration of the bituminous material is secured than it is possible to obtain with the more common methods; and it is believed that the roads so treated will require less frequent renewal of the treatment.

The problem for the greater part of the State, especially in the northern and northwestern counties where property values are low, is one of developing a large mileage of comparatively low-type road that will meet the demands of the traffic within the limits of the rather small funds that can be raised for the purpose. Certain of these counties lie in the path of through highways which carry a large amount of State and interstate traffic. Many of them are not in a position to issue bonds for the construction of expensive highways, yet the gravel roads which are within their present means are not capable of carrying the heavy traffic.

Experience has shown that when the traffic reaches 500 or more vehicles per day there is an annual loss of material on the surface of a gravel road of at least 1 inch. In some cases it reaches 1½ inches or more, depending on the traffic. A 1-inch loss on an 18-foot road is equivalent to a loss of approximately 400 cubic yards of material per mile, which, at an estimated cost of $2 per cubic yard delivered on the road, is about $800 per year. Besides this there is the dust nuisance, which is becoming a very serious problem during the heavy travel season. Many of the counties, too, realize that if they are not to exhaust their material deposits they must begin now to conserve the material for future needs. With these conditions in mind, the commission began experimenting with the surface treatment of gravel roads with light tars in 1922. In the first year it adopted the methods which had been used for a number of years in Maine, applying the tar to 20 miles of road.

THE MAINE TREATMENT

Following the Maine method of treatment, the surface was thoroughly scarified to a depth sufficient to remove all humps and depressions and care was taken to see that no ridges or solid strips of gravel were left after the scarifier had completed its operations. This was immediately followed up with the large-blade grader which was kept constantly on the surface until the road was shaped up to a uniform cross section and well compacted under traffic. The surface was then swept with a power sweeper, and in this operation the fine material was pushed off to the side. In a few spots hand sweeping was resorted to in order to remove all the fine material. This left a hard surface with the metal exposed. A priming coat of light tar, the characteristics of which are shown in Table 1, was then applied at the rate of about one-sixth gallon per square yard. This application was allowed to penetrate for at least 48 hours, after which the few spots needing it were given an additional treatment with the distributer or hand kettle. Following this application of tar, coarse torpedo sand was distributed along the shoulders in piles of about one-fourth cubic yard each, spaced about 25 feet apart. The second application of tar was then placed on the road at the rate of about one-third gallon per square yard, and immediately following this application sufficient sand was spread over the tar to keep it from running. The treatment results in a penetration of from one-half to three-fourths inch and forms a crust over the gravel.

TABLE 1.—*Tar for cold application*

General.	The tar shall be homogeneous.
Physical and chemical properties.	It shall meet the following requirements: 1. Specific gravity 25°/25° C. (77°/77° F.) not less than 1.100. 2. Specific viscosity at 40° C. (104° F.), 8 to 13. 3. Total distillate by weight: To 170° C. (338° F.), not more than 5 per cent. To 270° C. (516° F.), not more than 30 per cent. To 300° C. (572° F.), not more than 40 per cent. 4. Total bitumen (soluble in carbon bisulphide) not less than 90 per cent.
Methods of testing.	Tests of the physical and chemical properties of the tar shall be made in accordance with the following methods: 1. Specific gravity, Department of Agriculture Bulletin 1216, p. 45. 2. Specific viscosity (on first 50 c. c.) U. S. Department of Agriculture Bulletin 1216, p. 59. 3. Distillation test, U. S. Department of Agriculture Bulletin 1216, p. 62. 4. Total bitumen, U. S. Department of Agriculture Bulletin 1216, p. 47.

The 20 miles treated by this method in 1922 were followed by 60 miles in 1923 and 200 miles more in 1924, on the whole with considerable success. But it has been found that the roads require scarifying and reshaping and additional surface treatment each year.

THE NEW METHOD

The new method was first tried in 1923. The mile of road to which it was applied was surfaced with material which contained a considerable amount of coarse gravel. The surface was very loose and it was impracticable to sweep it without loss of much of the good metal, so the new method was tried as an experiment, and it has proved to be very successful.

The road was shaped to a uniform cross section with a large blade grader outfit. When this was completed, an application of tar at the rate of about one-third gallon per square yard was applied, traffic being allowed to use the road freely to mix the tar with the gravel. After about two hours the blade grader outfit, with the blade set at an angle of about 45 degrees and at a depth of about three-fourths inch was run over the surface, moving the material a few feet past the center of the road. A second application of about one-third gallon per square yard was then applied to the new surface. After this was done the material which was gathered at the center of the road was then moved back over the newly applied tar. This same process was followed for the other half of the road.

This method was found to give a penetration of between 1 and 1½ inches. The mile treated in 1923 required practically no maintenance during 1923 and only a few patches along the shoulders in 1924, amounting to less than $100 a mile. It is believed that it will

[1] Submitted for publication through the Highway Research Board, National Research Council.

not be necessary to scarify sections treated in this way, and that a light application of tar with an absorbent every second year will keep the surface in very good condition.

In 1924 the commission tried the same treatment on 12 additional miles of the Middleton-Sauk City road, which is one of the heaviest tourist roads, the traffic counts averaging between 2,500 and 3,000 vehicles a day during the summer months. The surface of this road is 21 feet wide and the treatment of the 12 miles was completed in 14 days. Although it rained on three or four days, the entire time is included in estimating the average cost of $1,287 a mile. The elements entering into this cost are 110,000 gallons of tar, at 12.95 cents per gallon; labor, $33 a day; rental, operation, and depreciation of equipment, $53 a day.

It must be understood, of course, that these tar treatments should not be employed unless traffic conditions warrant them. They do not take the place of a durable pavement, but they do conserve material, lay the dust, and provide an adequate surface until such time as funds are provided to build durable pavements.

(Continued from page 33)

advisable to call particular attention to the fact that, while average conditions have been used in this discussion in an effort to make the important points in it as clear as possible, no contractor should ever assume that his project is average. Many contractors are in financial difficulty to-day for no other reason than that in bidding on work of this kind they have failed to note that projects differ a great deal in this vital element—the average length of cut— and have assumed that the rate of production to which they were accustomed could be maintained, only to find that it could not. It is always necessary to scrutinize this detail with care, but it is doubly necessary in crossing State boundary lines. The style of design varies a great deal from State to State and perhaps in no particular more than in this one.

Tables similar to Table 4A, can be constructed readily by any coutractor who desires to do so, the output data being recomputed on the basis of the conditions governing for this particular outfit. To do this it is necessary that, over a reasonable period of time, he shall: (1) Measure the length of run per wagon load of material taken out; (2) time the loading period; (3) time the wait between loads; (4) time the turns; and (5) time the delays. This data should be collected for an hour each morning and afternoon for about two weeks, averaging the readings secured except those on delays, which should be added together and the sum divided by the total time during which studies have been made to obtain the percentage of lost time due to delays, breakdowns, etc. With this data the new table can be constructed, and once this basic data has been secured it will be possible to set about the more important task of bringing production into line with that which is shown in Tables 4B and 4C (depending on whether 1½-yard or 2-yard wagons are being used) to be reasonably attainable.

(Continued from page 39)

Soils having either a moisture equivalent above 20 per cent or a volumetric shrinkage above 15 per cent should be considered as doubtful subgrade material.

TENTATIVE CLASSIFICATION OF SUBGRADE SOILS

A tentative classification chart of subgrade soils is shown in Figure 10. The mechanical analysis has been taken as the basis of classification. Six classes have been established as follows: Silty sand, clayey sand; sandy silt, clayey silt; and sandy clay, silty clay. The class to which a soil belongs is determined by the predominating fraction, modified by the next predominating fraction. For example, a soil that has 20 per cent of sand, 30 per cent of silt, and 50 per cent of clay would be classified as a "silty clay" and be plotted as shown in Figure 10.

Undoubtedly this classification can be improved upon, but it will at least serve as a nucleus from which a more satisfactory one may be evolved as additional data are collected.

LANTERN SLIDES ILLUSTRATING HIGHWAY CONSTRUCTION AVAILABLE

The Bureau of Public Roads has prepared several sets of lantern slides illustrating methods of constructing various types of roads suitable for use in highway courses in engineering schools and colleges and before technical audiences. Each set consists of from 30 to 50 slides and is accompanied by a syllabus of a lecture for use with the slides. The titles of the lectures are as follows:

Highway Grading.
Sand-clay, Topsoil, and Gravel Roads.
Bituminous Surface Treated and Penetration Macadam Roads.
Mixed Asphalt Pavements.
Portland Cement Concrete Roads.
Brick Road Construction.

The slides are available for use on specific dates for periods not to exceed four days except during the summer season, when loans may be extended to two weeks. The borrower is required to pay the cost of transportation by express from Washington and return. A single set of slides packed for shipment weighs 15 pounds.

The bureau prefers to lend the slides one set at a time, but reservations may be made as far in advance as desired.

The sets of slides have been circulated among a number of schools and colleges during the past winter, and in several instances circuits have been arranged among two or more schools in the same section.

EFFECT OF CAPPING ON STRENGTH OF CORES DRILLED FROM CONCRETE PAVEMENTS

By R. E. BERGFORD, Assistant Engineer of Tests, Minnesota Highway Department

IN MAKING compression tests of concrete cylinders or of specimens of concrete drilled from actual structures, the importance of making the proper correction for the variation in the height of the cylinder relative to its diameter is a factor which has possibly not been sufficiently considered in the past. The necessity for definite information on this question has been felt by the writer for some time in connection with the tests made on cores drilled from pavements in Minnesota.

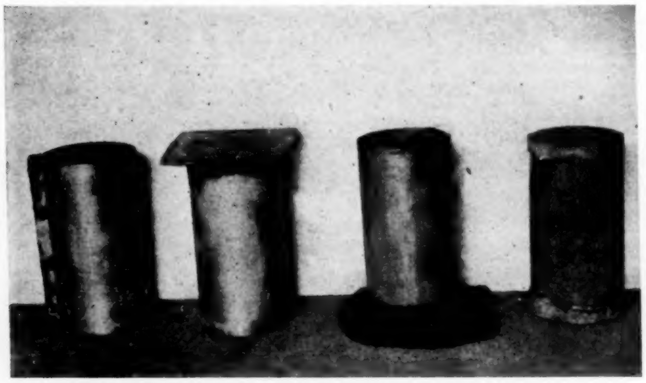

FIG. 1.—Illustrating the method of capping cores.

The diameter of the test specimen drilled is 4.35 inches and the height varies according to the thickness of the slab inspected. Cores are drilled not only from pavements constructed by the State but also from pavements constructed by various municipalities under a great variety of specifications. As is to be expected there is a considerable range in height of cores, heights varying from 3 to 10 inches.

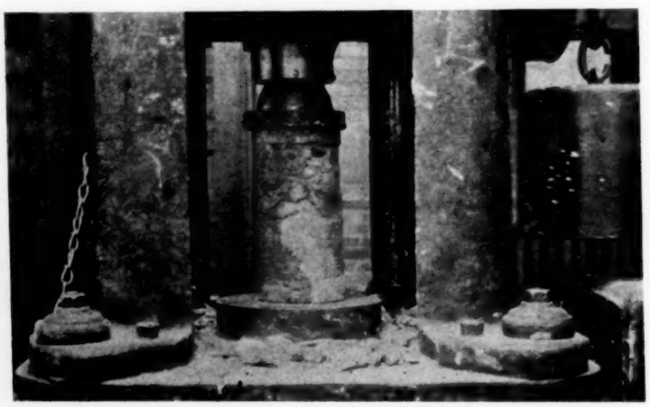

FIG. 2.—Showing core in place ready to be tested.

Owing to the great range in height of the test specimens, as well as to the more or less irregular surface on the end of the core which is in contact with the subgrade, the problem presented is, first, the best and most economical method of preparing the cores for the compression test, and second, the interpretation of results of compression tests on these cores.

The most satisfactory method of preparing the cores for a compression test would probably be to saw or grind both ends to a square and true surface. As this method necessitates the use of more or less elaborate machinery, the simpler method of capping the ends of the cores with a rich cement mortar has been adopted. The following procedure is used in capping the cores.

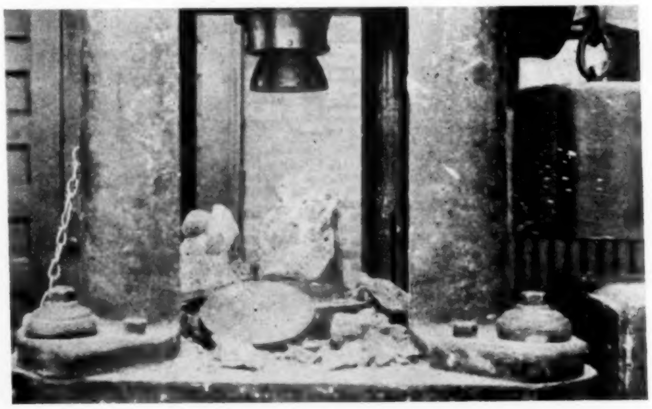

FIG. 3.—Showing core after testing.

METHOD OF CAPPING CORES

The end surfaces of the cores are first thoroughly brushed and washed in order to remove any dirt or loose material which might be adhering to the surface. The specimen is then placed in a galvanized iron form 4.35 inches in diameter and 8.7 inches high and centered accurately so as to give an equal thickness to the cap on each end.

The mortar used to cap the ends consists of a mixture of 4 parts of Portland cement to 1 part of sand by volume and enough water to make the mortar workable.

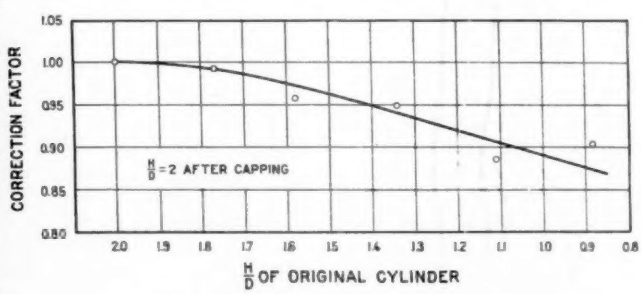

FIG. 4.—Effect of capping on test cylinders.

This mixture when properly cured is found to give a compressive strength greater than that of any of the cores. The capping material is placed in the form, tamped, rounded off with a trowel, and flattened off with a glass plate which is left in position for 24 hours. Damp sand is placed around the edge of the cap and left there for 24 hours in order to prevent checking or cracking of the mortar due to excessive shrinkage. At

the end of 24 hours the glass plate is removed and the opposite end capped in a like manner. After both ends of the core have been capped it is placed in a moist curing room and remains there until tested. The method of capping is illustrated in Figure 1. The method of testing the cores is illustrated in Figures 2 and 3.

The question naturally has arisen as to the correct interpretation of the test results. Very little data are available in regard to correction factors to be applied in the case of compression tests on cylinders of various heights. The recommended shape for a cylinder is one having a diameter equal to one-half its height, i. e., $\frac{H}{D}=2$. The cores as capped in the laboratory have a ratio of $\frac{H}{D}=2$ after they are capped. The variable is introduced by the fact that the capping material is not the same as the concrete composing the core.

In order that we might be able to determine the correct value for the compressive strength of cores thus tested, a series of concrete cylinders was made up, the diameter of each cylinder being 4.35 inches, and the heights ranging from 3.7 to 8.7 inches. The cylinders which are 8.7 inches high were taken as standard. The remaining cylinders were capped in the manner previously described so that the height after capping was equal to twice the diameter. The mix used in making the test specimens was 1:2:4 by volume. Four different aggregates, including sandstone, trap, gravel, and limestone, were used. The results of this investigation are shown in Figure 4, which shows the correction value to be applied to cores of varying heights. Each point in this graph represents the average of tests on 12 cores.

FIFTH INTERNATIONAL ROAD CONGRESS ANNOUNCED

The Fifth International Road Congress will meet at Milan, Italy, at the invitation of the Italian Government, from September 6 to 13, 1926.

The program announced for the congress includes the discussion of the following questions:

First Section.—Construction and Maintenance

First question.—Concrete roads.
Progress achieved in the use of materials for the construction of roads in cement-concrete.

Second question.—Bituminous and asphaltic roads.
Qualities required of the materials employed: Binder; aggregate.

Third question.—Standardization of tests for the following: Roads—materials.
Coal tar, bitumens, and asphalts.

Second Section.—Traffic and Administration

Fourth question.—Census of traffic.
Search for uniform international bases for adoption in every country.

Fifth question.—Development and planning of towns in interests of traffic.
Progress achieved in the general control of traffic in towns.

Sixth question.—Special roads reserved for motor traffic.
What conditions justify their being built.
The appropriate authorities for their initiation and construction.
Financial arrangements: Contribution from public funds; tolls; rules for traffic circulation and for exploitation.
Relationship and connection between motor roads and other highways in the interests of safety and the continuity of traffic generally.

An international exposition open to manufacturers or producers of materials and implements used in the construction and maintenance of roads, as well as to manufacturers of vehicles and accessories, will be held in connection with the congress.

The Italian committee of organization, in cooperation with the executive bureau of the Permanent International Association of Road Congresses, has arranged, in addition to the regular sessions, for a series of visits to modern roads built or under construction, notably the Autodrome of Monza, where a race for the grand prize will be run, and the new automobile highways which connect Milan with the Italian lakes. Visits are also scheduled to industrial plants and road-construction projects which will be under way at the time.

Information concerning the exposition may be obtained from the Secretariat de la Commission Italienne d'organisation du Veme Congres international de la Route, Via Sala 3, Milan (M. l'Ingenisur G. Lori, Secretaire General), or the Secretariat de l'Association Internationale Permanente des Congres de la Route, 1 Avenue d'Iena, Paris.

Details of the arrangements for the congress and the time schedule, as well as directions in regard to travel and lodging, will be published later.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

MARCH 31, 1925

STATES	FISCAL YEARS 1917-1925												BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
				FISCAL YEAR 1925										
	PROJECTS COMPLETED PRIOR TO JULY 1, 1924			PROJECTS COMPLETED SINCE JUNE 30, 1924			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	4,598,721.63	2,186,247.54	464.1	1,211,826.12	597,175.34	132.2	15,535,183.95	7,536,992.14	819.8	83,897.90	41,948.95	0.4	2,432,469.03	Alabama
Arizona	8,338,365.41	4,287,683.88	527.8	850,758.13	490,731.10	62.0	1,912,550.59	1,159,156.39	154.4	580,917.91	354,999.13	41.9	2,259,301.50	Arizona
Arkansas	11,094,751.31	4,424,345.63	944.4	1,826,278.21	782,661.32	78.9	6,842,562.82	2,888,860.18	371.1	439,930.06	175,800.66	24.1	2,054,896.21	Arkansas
California	12,999,075.03	5,647,148.17	533.7	7,728,789.52	4,173,069.86	308.4	9,570,563.27	4,622,869.53	240.2				5,122,854.44	California
Colorado	8,108,070.31	4,029,898.97	502.8	2,043,485.48	1,088,727.79	91.4	4,812,896.07	2,557,822.76	187.2	434,324.88	156,517.34	9.9	3,100,151.14	Colorado
Connecticut	3,062,872.02	1,269,558.60	73.6	344,021.87	163,383.00	8.2	3,114,792.92	980,844.04	50.8				1,442,210.36	Connecticut
Delaware	3,056,832.22	1,007,714.83	72.5	951,730.50	380,775.82	27.4	785,048.44	321,281.10	19.5				395,383.25	Delaware
Florida	961,134.07	461,470.92	48.8	1,903,234.92	924,017.05	43.4	8,936,479.45	4,276,067.21	240.8	116,547.09	91,547.09	0.1	1,426,662.73	Florida
Georgia	17,167,373.32	7,955,805.20	1,214.2	2,505,073.82	1,220,161.94	229.4	10,868,886.42	5,246,583.68	739.0	562,027.30	202,661.28	30.9	1,807,773.90	Georgia
Idaho	8,181,697.92	4,092,395.52	506.8	1,025,866.02	584,588.92	68.4	1,884,090.99	1,160,875.03	129.9	772,764.17	525,415.88	62.2	1,251,363.65	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7	9,498,957.56	4,649,408.31	307.6	7,989,434.22	3,887,002.14	273.5	2,671,148.05	1,322,589.49	95.8	4,489,424.73	Illinois
Indiana	7,577,444.16	3,655,540.97	225.7	4,612,589.31	2,222,109.13	152.9	12,569,653.34	6,136,323.77	406.2				4,237,111.13	Indiana
Iowa	23,195,778.19	9,237,031.86	1,682.9	3,319,941.92	1,516,911.81	238.1	5,746,438.71	2,635,611.59	429.3	2,920,333.58	1,231,126.05	112.2	2,785,851.69	Iowa
Kansas	17,084,136.48	6,043,176.80	502.7	6,930,775.77	2,750,857.38	244.2	14,746,138.35	6,033,891.84	642.9	1,310,537.95	453,819.17	45.5	2,091,903.81	Kansas
Kentucky	10,822,980.31	4,613,947.28	429.4	2,860,912.31	1,134,921.19	110.1	8,098,252.26	3,687,756.78	307.6	406,326.77	140,280.00		2,206,440.75	Kentucky
Louisiana	8,488,463.18	3,636,143.36	661.2	2,041,083.47	993,840.89	172.1	4,361,756.39	2,172,989.90	240.9	14,353.65	7,176.82		1,452,553.03	Louisiana
Maine	6,911,058.78	3,299,935.38	230.7	1,263,222.53	607,934.95	50.7	749,878.17	350,363.39	24.2				1,516,878.28	Maine
Maryland	6,760,044.42	3,213,321.78	243.2	646,410.32	307,486.47	25.5	2,464,768.03	1,065,404.17	76.2	337,942.11	122,411.22	8.8	576,109.36	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8	2,128,343.98	788,018.34	39.7	4,794,626.96	1,430,934.20	74.4	1,234,605.08	354,646.77	21.4	2,330,571.47	Massachusetts
Michigan	13,434,135.07	6,060,612.23	494.5	2,165,559.55	994,055.92	101.6	14,965,650.26	7,044,686.58	479.4	163,170.00	81,585.00	5.4	3,924,059.27	Michigan
Minnesota	24,037,561.24	9,885,843.07	2,292.0	6,378,124.65	2,852,798.97	429.2	6,294,034.56	2,923,600.00	662.5	679,082.36	46,300.00	67.8	1,734,027.96	Minnesota
Mississippi	7,888,193.89	3,828,941.39	655.0	1,969,486.65	945,591.68	141.4	8,320,046.33	4,180,767.52	485.0	77,107.38	36,968.23	4.5	1,830,964.18	Mississippi
Missouri	11,352,027.70	5,245,899.18	803.5	4,226,155.25	2,092,916.56	242.8	23,815,757.38	9,747,509.61	784.4	4,593,722.03	1,173,042.31	154.6	2,098,547.34	Missouri
Montana	8,867,279.16	4,384,335.12	791.4	1,289,321.25	933,188.03	130.2	1,885,734.50	1,380,489.53	161.4	1,038,200.22	590,707.66	117.2	5,226,169.66	Montana
Nebraska	7,876,337.16	3,714,691.59	1,440.4	791,712.26	381,242.14	60.4	8,066,148.46	3,952,701.66	874.1	413,267.76	206,633.87	45.6	4,777,645.74	Nebraska
Nevada	3,460,245.52	1,853,624.98	225.6	1,446,557.71	1,228,225.07	131.4	4,300,066.51	3,622,200.69	351.5	155,693.56	131,383.28	10.8	1,002,962.98	Nevada
New Hampshire	3,076,750.19	1,487,867.56	171.3	1,052,452.40	481,514.29	35.7	778,364.10	372,998.07	25.1	60,651.77	29,200.25	2.6	429,008.81	New Hampshire
New Jersey	7,623,795.12	2,661,531.49	148.7	3,757,997.15	991,122.25	59.6	7,267,004.53	2,288,562.35	41.5	303,401.87	88,599.00	5.9	1,494,513.91	New Jersey
New Mexico	5,306,286.45	2,758,849.68	714.3	2,167,396.87	1,377,821.90	224.2	5,663,914.48	3,710,640.73	539.5	250,983.39	154,354.77	16.7	1,772,830.92	New Mexico
New York	18,862,742.49	8,257,844.44	572.7	4,371,833.80	1,810,063.42	121.1	27,762,574.84	10,358,069.38	612.7	6,455,088.00	1,870,970.00	121.8	8,068,296.76	New York
North Carolina	12,567,732.97	5,676,757.66	884.7	6,093,681.22	2,189,158.07	169.8	7,802,035.12	3,037,940.48	206.2	1,791,845.30	851,774.46	56.7	2,237,788.33	North Carolina
North Dakota	9,088,973.11	4,418,505.42	1,587.9	1,707,265.90	833,931.18	325.6	2,486,235.72	1,248,727.03	347.1	579,726.71	289,863.29	72.2	2,753,328.08	North Dakota
Ohio	33,122,751.43	11,879,917.99	962.5	7,596,805.64	3,099,875.94	207.1	8,514,974.91	2,964,707.50	250.2	2,784,105.61	1,049,339.15	80.5	3,935,911.42	Ohio
Oklahoma	12,986,865.26	5,888,852.03	497.3	5,699,897.38	2,765,414.67	246.0	6,385,181.94	3,054,129.10	295.5	2,033,937.26	913,789.21	79.2	1,669,622.99	Oklahoma
Oregon	12,082,873.17	5,819,093.79	656.6	2,162,545.40	1,274,243.08	140.2	2,409,577.77	1,386,773.92	105.7				1,205,716.21	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7	3,160,057.54	1,190,520.57	66.1	31,710,921.89	5,724,702.50	354.4	12,532,653.38	4,473,268.00	301.8	2,458,553.14	Pennsylvania
Rhode Island	1,774,397.25	779,227.96	46.0	854,098.96	340,460.13	18.8	1,171,551.79	341,168.84	15.8	714,691.45	197,520.75	11.9	640,288.32	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4	1,822,899.07	846,189.44	280.6	6,094,519.84	2,293,646.95	391.6	965,012.37	261,412.93	19.9	1,214,800.46	South Carolina
South Dakota	8,674,597.86	4,244,636.27	989.8	2,874,573.89	1,498,821.92	429.1	6,169,362.98	3,009,035.89	798.9	471,109.62	235,554.79	106.7	945,651.13	South Dakota
Tennessee	6,805,683.35	3,313,936.07	259.6	5,721,124.74	2,802,118.58	196.2	11,995,215.60	5,457,985.85	430.6	656,537.10	323,649.70	33.8	1,749,931.80	Tennessee
Texas	42,341,998.56	16,190,624.91	3,122.8	8,755,960.45	3,580,315.53	546.7	23,062,112.73	9,584,555.77	1,422.7	4,977,485.76	2,152,613.76	329.4	4,631,818.03	Texas
Utah	3,304,423.75	1,895,805.92	219.0	1,596,373.90	1,028,206.53	147.3	3,914,748.36	2,560,601.77	225.7	318,700.99	219,171.60	31.5	1,259,154.28	Utah
Vermont	1,922,114.16	942,769.12	74.4	641,963.65	308,451.42	19.2	1,632,633.82	776,217.63	40.0	10,699.53	5,349.76		866,816.07	Vermont
Virginia	10,035,301.49	4,801,782.43	562.5	2,368,536.37	1,136,082.48	90.2	9,437,249.00	4,330,933.38	324.1	1,683,159.95	703,141.78	62.8	1,070,725.93	Virginia
Washington	11,384,615.67	5,290,895.45	457.0	1,172,750.16	511,294.59	51.9	3,367,073.68	1,599,900.00	134.9	296,296.71	134,000.00	9.0	1,469,574.96	Washington
West Virginia	5,489,747.95	2,365,041.53	255.6	1,853,452.91	865,251.80	71.1	4,166,291.65	1,791,537.78	127.9	2,458,182.33	900,745.56	63.9	628,850.33	West Virginia
Wisconsin	18,753,903.15	7,441,033.57	1,325.3	3,001,359.02	1,452,667.68	121.0	2,317,433.76	1,096,311.36	109.7	53,417.25	26,708.00	3.9	5,535,038.39	Wisconsin
Wyoming	6,127,625.61	3,078,098.70	687.6	2,629,027.49	1,626,626.97	290.5	2,736,020.87	1,702,071.25	122.2	121,396.44	78,481.00	9.1	1,137,020.08	Wyoming
Hawaii										$ 342,277.22	$ 97,440.00	6.5	$ 633,810.00	Hawaii
TOTALS	$ 549,655,391.27	$ 237,852,399.82	34,452.9	$ 143,022,372.98	$ 66,814,951.42	7,485.5	$ 359,976,438.80	$ 159,694,802.96	16,148.2	58,867,259.82	22,504,507.86	2,284.9	111,383,337.94	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 95,351,146.96 Federal aid $ 41,277,405.13 Miles 3,759.9

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage in the United States, 1914. A Summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
*583. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

THE GASOLINE TAX IN 1924

States	Tax rate per gallon on Dec. 31, 1924	Gross receipts 1924	Amount applied to road work under supervision of State highway departments
	Cents		
Alabama	2	$1,738,661	----------
Arizona	3	730,838	$365,419
Arkansas	4	2,768,535	2,268,535
California [1]	2	11,993,222	5,996,611
Colorado	2	1,725,957	819,830
Connecticut [1]	1	978,283	978,283
Delaware	2	304,392	304,392
Florida	3	3,658,677	2,575,199
Georgia	3	4,527,471	1,509,157
Idaho	2	545,672	545,672
Illinois	----------	(No tax)	----------
Indiana	2	4,925,372	4,187,855
Iowa	----------	(No tax)	----------
Kansas	([2]) -	(No tax)	----------
Kentucky	3	1,660,938	1,660,938
Louisiana	2	1,335,320	1,335,320
Maine	1	522,250	522,250
Maryland	2	1,588,422	1,111,895
Massachusetts	----------	(No tax)	----------
Michigan	([2]) -	(No tax)	----------
Minnesota	----------	(No tax)	----------
Mississippi [1]	3	1,648,748	787,319
Missouri	----------	(No tax)	----------
Montana	2	619,295	123,859
Nebraska	----------	(No tax)	----------
Nevada	2	162,596	60,000
New Hampshire	2	587,845	587,845
New Jersey	----------	(No tax)	----------
New Mexico	1	194,983	185,234
New York	----------	(No tax)	----------
North Carolina	[2] 3	4,529,048	[3] 4,520,000
North Dakota	1	442,969	----------
Ohio	----------	(No tax)	----------
Oklahoma	2.5	2,983,501	1,544,600
Oregon	3	2,698,778	2,582,890
Pennsylvania	2	9,089,541	----------
Rhode Island	----------	(No tax)	----------
South Carolina [1]	3	2,186,137	728,889
South Dakota	2	1,205,155	1,106,635
Tennessee	[2] 2	1,812,235	1,812,235
Texas	1	3,892,769	2,919,577
Utah [1]	2.5	684,361	682,985
Vermont [1]	1	230,865	230,865
Virginia	3	3,313,188	[3] 2,208,571
Washington	2	2,635,411	2,635,411
West Virginia	2	1,231,944	1,231,944
Wisconsin	----------	(No tax)	----------
Wyoming	[2] 1	200,319	200,319
District of Columbia	2	380,792	380,792
Totals	----------	$79,734,490	$48,711,792

[1] Data given cover calendar years, except for the following States, where fiscal years end as shown: California, Jan. 31; Connecticut, June 30; Mississippi, South Carolina, Utah and Vermont, Nov. 30.

[2] To date in 1925, these States have enacted new gasoline tax rates effective as follows: Kansas, 2 cents (May 1); Michigan 2 cents (Feb. 15); North Carolina, 4 cents (Mar. 5); Tennessee, 3 cents (Feb. 9); Wyoming, 2½ cents (Mar.).

[3] Approximate.